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AT

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CONTENTS.

PAGE

No. 1. — Notes on the Geology of the Iron and Copper Districts of Lake Superior. By M. E. WADSWORTH. (6 Plates) 1

No. 2. — The Felsites and their Associated Rocks, North of Boston. By J. S. DILLER 165

No. 3. — On an Occurrence of Gold in Maine. By M. E. WADSWORTH . . 181

No. 4. — A Microscopical Study of the Iron Ore, or Peridotite of Iron-Mine Hill, Cumberland, Rhode Island. By M. E. WADSWORTH 183

No. 5. — Observations upon the Physical Geography and Geology of Mount Ktaadn. By C. E. HAMLIN. (2 Plates) 189

No. 6. — Report on the Recent Additions of Fossil Plants to the Museum Collections. By LEO LESQUEREUX 225

No. 7. — The Great Dike at Hough's Neck, Quincy, Mass. By JOHN ELIOT WOLFF 231

No. 8. — On some Specimens of Permian Fossil Plants from Colorado. By LEO LESQUEREUX 243

No. 9. — On the Relations of the Triassic Traps and Sandstones of the Eastern United States. By WILLIAM MORRIS DAVIS. (3 Plates) 249

No. 10. — The Folded Helderberg Limestones, East of the Catskills. By WILLIAM MORRIS DAVIS. (2 Plates) 311

No. 11. — The Azoic System and its Proposed Subdivisions. By J. D. WHITNEY and M. E. WADSWORTH 331

Bulletin of the Museum of Comparative Zoölogy,
AT HARVARD COLLEGE.
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No. I.

NOTES ON THE GEOLOGY OF THE IRON AND COPPER DISTRICTS OF LAKE SUPERIOR.

BY M. E. WADSWORTH.

CAMBRIDGE:
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CONTENTS.

PAGE
INTRODUCTION 1

THE IRON DISTRICT 1-76
Historical 1-26
Historical Summary 26, 27
Methods of Observation 27, 28
The Jasper and Iron Ore 28-36
The Basic Intrusive Rocks, Schists, and Felsite . . 36-49
"Soft Hematites" 49-52
Granite, Gneiss, and Quartzite 52-60
Potsdam Sandstone 60
Peridotite and Serpentine 60-66
General Discussion and Results 66-76

THE COPPER DISTRICT 76-132
Historical 76-107
Historical Summary 107-109
The Traps 109-113
The Sandstones and Conglomerates 113-122
The Veins and Copper Deposits 123-127
Conclusions 127-132

BIBLIOGRAPHY 133-157

DESCRIPTION OF THE PLATES 159-164

No. 1.—*Notes on the Geology of the Iron and Copper Districts of Lake Superior*. By M. E. Wadsworth.

There are probably no regions of like extent in the United States that have attracted greater interest or attention than the Copper and Iron districts of Lake Superior. The most discordant views have been held concerning their geology, and the origin of their ore deposits. There are also probably no districts in this country which have been more accurately studied, taking all of the conditions into consideration, than these were some thirty years ago. The geology, including the origin of their ore deposits, was then, for the time and methods of study, stated with a remarkable degree of accuracy, so far as it has been our province to observe or judge. It would not, then, be our duty to write concerning these districts, were it not that the almost universal belief of geologists at the present time regarding one, and in some respects the other district, is so entirely at variance with the facts as we interpret them. Before giving the facts it is necessary to present to the reader some of the various ideas held regarding the geology of both districts. We shall, however, in the main confine ourselves to those parts which we have visited, except so far as observations elsewhere have a bearing upon our work, or upon the questions which we wish to discuss.

It seems best to take up these views in chronological order, even if it does impart a dictionary flavor to this paper. First in order, then, we propose to discuss

The Iron District.

The earliest writer that it is necessary to quote here is Henry R. Schoolcraft, whose Narrative Journal of Travels, etc. was published at Albany in 1821. He speaks of the granite at Granite Point (p. 158), and of its being traversed by veins of greenstone trap. He gives the composition of the former rock, and advances his reasons for considering that it occupied its present position before the deposition of the overlying sandstone. He does not attempt to give the age of the sandstone, although he thinks "its position would indicate a near alliance to the 'old red sandstone.'"

Dr. Douglas Houghton, in his first Report on the Geology of Michigan, remarks upon the "appearance of primary and trap rocks forming mountain chains, and the great disturbance which has taken place since the deposition of the red sandstone," and says that this sandstone in the vicinity of Granite Point is "scarcely disturbed, resting upon nobs of primary rocks."[*] In Dr. Houghton's Fourth Annual Report, for 1841,[†] the rocks of this region are described as primary ones, consisting chiefly of granite, sienite, sienitic granites, and greenstone with metamorphic rocks on their flanks, forming a stratified series consisting of "talcose, mica and clay slates, slaty hornblende rock, and quartz rock; the latter rock constituting by far the largest proportion of the whole group." He considered that the granite passed "almost insensibly into a serpentine rock." (*l. c.*, p. 482.) In like manner, he thought that the granites on the southeasterly side of the district changed going northwesterly into a greenstone, and that the dikes traversing these granites were identical with the greenstone, having been injected into the granite. His serpentine bears a close resemblance to greenstone, and he states that "possibly a more close examination may show it to be a simple series of dikes, lying parallel to the line of cleavage of the slate rocks." (*l. c.*, p. 494.) Regarding Presque Isle he says: "This point of land has its origin from the simple elevation of a mass of trap rock, which rises on the north in abrupt cliffs, varying from twenty to sixty feet in height. The trap is mostly greenstone, though portions of it are so largely impregnated with a dark-colored, almost black serpentine, as to deserve the name of serpentine rock. The knob of trap under consideration is possessed of additional interest, from the unequivocal evidence of uplift, as also from the manner in which these evidences are exhibited. The cliffs of trap occupy the very extremity of the point, while the neck and central portions are made up of conglomerate or trap tuff and sand-rock, resting upon the trap. These upper rocks also appear upon the immediate coast, in cliffs of from twenty to sixty feet in height, and in many places they are seen resting directly upon the trap. The stratification of these sedimentary rocks has been very much disturbed, and they invariably dip, at a high angle, in all directions from the trap itself. The character of both rocks, at the immediate line of junction, is almost completely lost, and the evidences of change most unequivocally marked. But the most curious feature of the whole is, that the sedimentary rocks, for a distance of several hundred feet, have been completely shattered or broken into minute fragments, which, having retained their original position, were again cemented by the injection of calcareous matter. This injection has filled the most minute fissures, and so perfect is it, that, in looking upon the face of a mural cliff of these rocks, the veins may be easily seen at a distance of many rods, forming, as it were, a complete net-work over the cliff, and so minute is it, that a single hand specimen frequently contains many hundreds of these veins." (*l. c.*, p. 492.)

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[*] History of Michigan, by J. H. Lanman, (New York, 1839,) pp. 348, 352.

[†] Joint Documents, Michigan, 1841, pp. 471-607.

In this Report is the first mention of iron ore in this district that we have seen. He gives amongst the minerals of the "Metamorphic group of Rocks," "scaly red oxide of iron" and "hæmatite." Regarding the latter he says: "Although the hæmatite is abundantly disseminated through all the rocks of the metamorphic group, it does not appear in sufficient quantity, at any one point that has been examined, to be of practical importance." (*l. c.*, p. 504.)

In Dr. Houghton's Fifth Report some remarks were made both upon this district and upon the copper district, but nothing of special importance was added.* Mr. George N. Sanders, in a report to the Ordnance Office,† speaks of collecting "rich specimens of iron ore" on the Menomonee River. In the same documents for 1845 – 46 ‡ are given reports for the year 1845, by William A. Burt and Bela Hubbard.§ Mr. Hubbard evidently considered that the ridges in the Marquette Iron District were composed in the centre of eruptive rocks, but not outcropping, being "capped as well as flanked by the metamorphosed rocks." He states in regard to the metamorphic rocks that "these rocks are throughout pervaded by the argillaceous red and micaceous oxydes of iron, sometimes intimately disseminated, and sometimes in beds or veins. These are frequently of so great extent as almost to entitle them to be considered as *rocks.* The largest extent of iron ore noticed is in township 47 north, range 26 west, near the corners of sections 29, 30, 31, 32. There are here, too, large beds or hills of ore, made up almost entirely of granulated, magnetic, and specular iron, with small quantities of spathose and micaceous iron. The more northerly of these hills extends in a direction nearly east and west, for at least one fourth of a mile, and has a breadth little less than 1,000 feet, the whole of which forms a single mass of ore, with occasional thin strata of imperfect chert and jasper, and dips north 10 degrees, east about 30 degrees. At its southerly outcrop, the ore is exposed in a low cliff, above which the hill rises to the height of 20 or 30 feet above the country on the south. The ore here exhibits a stratified or laminated structure, and breaks readily into sub-rhomboidal fragments, in such a manner as will greatly facilitate the operation of quarrying or mining the ore. This bed of iron will compare favorably, both for extent and quality, with any known in our country." (p. 22.) The sandstone is said to be found frequently "surrounding, and in contact with, the uplifted masses of igneous rocks, and is then invariably much altered both in appearance and textures, and may, under such circumstances, fairly be considered as metamorphic." (p. 23.)

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* Joint Documents, Michigan, 1842, pp. 436 – 441.

† Senate Documents, 28th Cong. 2d Sess., 1844 – 45, XI., Doc. 175, p. 11.

‡ 29th Cong. 1st Sess., VII., Doc. 357.

§ See also Senate Documents, 1849 – 50, 31st Cong. 1st Sess., III. 802 – 842, and The Mineral Region of Lake Superior, by J. Houghton and T. W. Bristol, (Detroit, 1846,) pp. 3 – 39.

In the report of Mr. A. B. Gray to the Ordnance Bureau,* galena and copper pyrites were said to exist quite abundantly, and that it was probable that rich tin ores would be found. Mr. Samuel Peck is credited with having first explored the iron region, and called attention to the existence of that mineral (*l. c.*, pp. 15, 16).

Prof. H. D. Rogers † stated that the rocks in the vicinity of the Chocolate and Carp Rivers (Huronian of Brooks) were "the equivalents undoubtedly of the Primal sandstone and Primal slate," or the Potsdam sandstone of the New York survey.

Mr. William A. Burt, in his report "with reference to mines and minerals for 1846," ‡ (pp. 849 - 852,) described "fourteen beds of magnetic iron ore" in this district. Mr. Bela Hubbard in his report for the same year (*l. c.*, pp. 901 - 905) advances some views upon the passage of one rock into another, as follows: "A feature peculiar to all the rocks of the country alluded to as granitic, is their occasional trappose character, and the rare occurrence of mica. The constituents which make up the greater part are quartz, felspar, and hornblende; the proportions of which vary extremely. Thus, while the general character is that of true *sienite*, the absence of quartz in a distinct form often produces a *greenstone*, while frequently the last-mentioned mineral predominates almost exclusively, constituting a true *hornblende rock*, which is generally of a crystalline structure, and usually has a slaty cleavage. Again, quartz becomes the predominant mineral, constituting what may be denominated a *quartzite*. . . . . In a few instances talc was found to take the place of hornblende, constituting a *protogine*. . . . . We accordingly find the sienites assuming a trappose character, and often undergoing so insensibly the change from a granitic to trappean rock, that it is impossible to distinguish where one begins, and the other ends. In the operation of these changes, the excess of silica may be called in to account for the metamorphic rocks of the country, and particularly for the abundance of pure quartz in rocks and veins. . . . . Not only have changes accompanied the contact of trap with other rocks, such as have usually been referred to the heat of the injected mass when in a state of fusion, but equally marked changes have accompanied the conjunction of the *sienites* with the sandrock under circumstances where the same causes cannot be called in; for the latter gives evidence of having been deposited subsequently to the formation and uplift of the former, and the *sienite* was as often observed to have partaken of the change as the sedimentary rock. Without going further into detail of facts of merely scientific nature, it may be sufficient to say that it seems more reasonable to attribute the metamorphism which has taken place in both rocks rather to galvanic and chemical action than to igneous causes, which are so generally called in to account for all these phenomena. The rocks designated upon the maps as metamorphic, occupy, as it were, beds amid the surrounding primary rocks; and while we would avoid any theoretic conclusions as to their origin, it may be stated that, throughout the whole primary region, the limits of each rock, except in the case of dikes, are seldom distinctly defined, but one passes into the other by gradual transition; so that often rocks of distinct name and character can be considered only as members of the same formation, the constituents of which have become differently aggregated."

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* Executive Documents, 29th Cong. 1st Sess., Vol. VII., No. 211, 1845 - 46, pp. 2 - 23. Am. Jour. Sci., (2,) Vol. V., 1848, p. 151.

† Proc. Bost. Soc. Nat. Hist., April 1st, 1846, II. 125.

‡ Senate Documents, 31st Cong. 1st Sess., 1849 - 50, III. 371 - 935.

Mr. J. W. Foster, in his report to Dr. Charles T. Jackson, dated September 28, 1848,* describes part of the iron region. The rocks are considered to be older than the sandstone, which is regarded as belonging to the oldest palæozoic rocks. Previous to this, Dr. John Locke attempted to describe the district in part; but his account appears to be of no value, except from an historical point of view.† We would, however, call attention to his bathetic description of the "Pictured Rocks" (pp. 189 – 191).

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* Senate Documents, 2d Sess. 30th Cong., 1848 – 49, III., Doc. 2, pp. 159 – 163; Executive Documents, III., Doc. 12, pp. 159 – 163.

† Senate Documents. 1st Sess. 30th Cong., 1847 – 48, II. 186 – 189, Oct. 25, 1847.

Pages 371 – 801 of a publication previously mentioned* is devoted to the publication of the reports of Dr. C. T. Jackson and his corps. This document is one of the curiosities of geological literature, — a *rara avis*. It was printed in such a manner that in many cases it would be very difficult, if not impossible, to determine who were the authors of the different parts of the text, were it not for the fusillade all along the line.

Dr. Jackson gives (pp. 477 – 479) some account of his first knowledge of the iron ore (1844) in this district, but it seems that he never visited the region himself. Dr. John Locke, in his field-notes for 1847 (*l. c.*, pp. 572 – 605), describes the rock of Presque Isle as "a light-green trap, reticulated with white veins near the junction of the sandstone, with which the trap is apparently interfused." He also describes the iron region to some extent. He considers that the trap rocks are frequently interfused with the metamorphic ones in the district, and states that certain quartz veins "deserve close examination for gold, silver, and other rare metals. Veins of this description, if they prove important, can undoubtedly be found in the metamorphic rocks."

It is well known that the early explorers had to contend with very great difficulties in their work in this region; but probably none ever suffered such aggravation of spirit as did Dr. Locke, when, on July 27, 1847, his compass ran wild and its poles stood seventeen feet and eight inches apart, unless it was when he found his provisions were only a few sticks of wood and a bucket of bean soup.† Mr. J. W. Foster, in his report to Dr. Jackson, dated May 26, 1849 (*l. c.*, pp. 773 – 785), gives a description of the iron region, as studied by him in 1848. He regards the iron ores as sedimentary deposits. "These beds, so far as I have observed, present a marked similarity in mineralogical characters, and derive their origin from common causes, and those were *aqueous*. The jointed structure and waved stratification of some of the beds prove that *igneous* causes have operated, since their deposite, to modify and change their character." (p. 776.) "Here, they certainly bear upon their surfaces strong marks of their mechanical origin. They are regularly stratified, and often contain thin seams of silex in minute grains, so that a specimen, on its cross fracture, resembles ribbon-jasper. The lines of stratification can readily be distinguished from those of lamination. Like the slates, they are often found contorted and wrinkled, and the same facts could be adduced in both cases to prove their common origin." (p. 779.) This description belongs, for the most part, to the

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* Senate Documents, 1st Sess. 31st Cong., 1849 – 50, III. 371 – 935.

† Senate Documents, 1st Sess. 30th Cong., 1847 – 48, II., Doc. 2, p. 190.

Menomonee region, but part of the Marquette district is included. The granites were classed by him as igneous rocks.

Printed in the midst of these reports is one from Messrs. Foster and Whitney (*l. c.*, pp. 605 – 626) made to the Land Office and Interior Department, dated November 5, 1849, which gives some account of the Iron and Copper districts. The iron is stated to occur in the metamorphic formation. "This formation consists of hornblende, talcose, and chlorite slates, with associated beds of hornblende and felspar rocks, evidently trappean in their origin." (pp. 609, 610.)

December 19, 1849, Professor J. D. Whitney gave some account of this region before the Boston Society of Natural History.* The iron ore was then stated to be of igneous origin. In a report transmitted to the Interior Department, October 25, 1850,† Messrs. Foster and Whitney state that the sandstone is of Potsdam age. "Below the whole of the silurian rocks we meet with a class of deposites which were probably detrital in their origin, but which have been so metamorphosed as essentially to change their structure. They are destitute of organic remains, and contain imperfect traces of stratification. They consist of various schists and beds of quartz, marble, and specular and magnetic oxide of iron. We have termed these various groups the *azoic system*, — a system which, thus far, has not been fully recognized in Europe, but the existence of which the results of this survey, as well as that of Canada under Mr. Logan, have fully demonstrated. Upon the upturned edges of these slates the Potsdam sandstone is found reposing in a nearly horizontal position. They form the nucleus around which the newer rocks have been deposited, and are extensively developed between the shores of the two lakes. They are the depositories of the most extensive beds of iron known in the world."‡ The term "Laurentian" was first proposed by Sir William E. Logan, in 1853,§ for the metamorphic rocks underlying the Potsdam sandstone north of the St. Lawrence, although it had been used some years before by Mr. Edward Desor to designate certain drift deposits in the St. Lawrence valley, and by the law of priority the name should have been retained in its original sense.

May 5, 1851, a paper was presented to the American Association‖

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[*] Proceedings, III. 210 – 212.

[†] Senate Documents, 2d Sess. 31st Cong., 1850 – 51, II., Doc. 2, pp. 147 – 152.

[‡] See also Bull. Soc. Geol. France, 1850 – 51, (2,) VIII. 89 – 100.

[§] Report of Progress Geol. Survey of Canada, 1852 – 53, p. 8.

[‖] Proceedings, V. 4 – 7.

by Messrs. Foster and Whitney, entitled, "On the Azoic System, as developed in the Lake Superior Land District," in which the distribution of the azoic rocks in North America was briefly pointed out. The term Azoic was adopted by them from Murchison and De Verneuil,* but limited in its signification by Foster and Whitney "to a class of rocks supposed to be detrital in their origin, and to have been formed before the dawn of animal or vegetable life. It comprises the most ancient of the strata which form the crust of the earth, and occupies a distinct position in the geological column; being below the Potsdam sandstone. In this district, the rocks consist, for the most part, of gneiss, hornblende, chlorite, talcose, and argillaceous slates; interstratified with beds of quartz, saccharoidal marble, and immense deposits of specular and magnetic oxide of iron. Most of these rocks appear to be of detrital origin, but to have been greatly transformed by long-continued exposure to heat. They are sub-crystalline, or compact, in their texture, and rarely present unequivocal signs of stratification. They have been subject to the most violent dislocations. In one place, the beds are vertical; in another, reversed; and in another, present a series of folded axes. Intermingled with them is a class of rocks whose igneous origin can hardly be doubted, and to whose presence the metamorphism so characteristic of this series is, in a measure, to be ascribed. They consist of various proportions of hornblende and feldspar, forming traps and basalts; or, where magnesia abounds, pass into serpentine rocks. They appear, in some instances, to have been protruded through the pre-existing strata, in the form of dikes or elvans; in others, to have flowed in broad lava streams over the ancient surface; and in others, to have risen up through some wide-expanding fissure, forming axes of elevation." Gaseous sublimations, intense pressure, and electro-chemical agencies were thought to have assisted in the metamorphism, as well as the plutonic masses. "Since the theory of metamorphism has been generally adopted, many of the rocks which were formerly regarded as igneous are now referred to aqueous agency, and their transformations traced to the presence of erupted rocks. They here cited numerous examples of metamorphism, showing that argillaceous schist is transformed into gneiss; sandstone into compact vitreous quartz; and limestone into saccharoidal marble, when brought in contact with eruptive masses. They therefore inferred, that these obscurely bedded rocks, — such as gneiss, and the crystalline schists, — were of sedimentary origin; that no rock was to be regarded as igneous, unless it occur in vast, irregular masses, like granite; in dome-shaped, or crater-like summits, as basalt, or trachyte; in long lines, as dykes or elvans cutting through the incumbent strata; in ramifying veins, like granite; or broad lava sheets, like trap. Many eminent geologists maintain that the lowest stratified rocks are but portions of the Silurian System, and that, from long-continued exposure to heat, the lines of stratification have become obscure, and all traces of organic remains obliterated. Our observations in this district (they remarked) have led us to a different conclusion."

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* Russia and the Ural Mountains, I. 10.

"The evidence is ample that the base of the Silurian System reposes upon their upturned edges, and that the causes by which the metamorphism of the former was effected had ceased to operate before the deposition of the latter. Between the two systems there is a clear and well-defined line of demarkation. It forms one of those great epochs in the history of the earth, where the geologist can pause, and satisfy himself of the correctness of his conclusions. On the one hand he sees evidence of intense and long-continued igneous agency, and, on the other, of comparative tranquillity and repose. . . . . The Azoic Series was characterized by immense deposits of specular and magnetic oxide of iron. This might, with great propriety, be denominated the IRON AGE of Geology. . . . . It was evident that these strata were everywhere plicated and folded, and that the observer passed over a repetition of beds, instead of a succession of beds; but that the strata, throughout the whole region, had been so shattered by earthquakes, and so metamorphosed, by direct or transmitted heat, that it was impossible to identify them, except over limited areas." Later, attention was called to the point that this continent was as old as the European, if not older.* The above points were given in much greater detail in Messrs. Foster and Whitney's "Report on the Geology of the Lake Superior Land District. Part II. The Iron Region, together with the General Geology." Transmitted November 12, 1851.† Such portions of this report as it is necessary to note will be touched upon below.

The range of quartzose hills extending from Carp River by Teal Lake was described to some extent, and was regarded as formed from a metamorphosed sandstone. Enclosed fragments of jasper and slate, lines of bedding, and obscure traces of ripple-marks were said to have been seen in this quartzite (*l. c.*, pp. 15, 16). Of Presque Isle they said: "The outline of this mass is very irregular, and resembles an immense consolidated lava-stream, except that the vesicular structure is wanting. To the north, the surface of the igneous rock is bare; but, on the eastern side, it is covered in places with a rudely stratified mass, which appears to have been deposited in the inequalities of the preexisting surface. It resembles a volcanic sand, or ash, portions of it being composed of a scoriaceous mass of a light-brown color, and reticulated with numerous veins of a white mineral, portions of which are calcareous, and others silicious." (*l. c.*, pp. 121, 122; see, also, pp. 18 and 92.)

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* Same Proceedings, page 151. See also entire article, pp. 136 – 151.

† Senate Documents, Spec. Sess. 32d Cong., III., 1851.

This rock was thought to be of prior origin to the sandstone. The sandstone was regarded as Potsdam, and as the same rock as that on Keweenaw Point. It was pointed out that this sandstone rests nearly horizontally on the water-worn edges of the nearly vertical quartzite. (*l. c.*, pp. 122, 123.) The iron ores were regarded as of igneous origin, forming intrusive masses and overflows, principally the latter, like a lava, but consolidated under pressure of a deep ocean. Sublimations of the iron occurred while the denudation and deposition of the eruptive masses that were by the shore-line aided in making the different formations. After this series of igneous and aqueous orebeds were laid down, "the whole series of beds, slaty, quartzose, ferruginous and trappean, were elevated, and, in all probability, folded, perhaps at the epoch of the elevation of the granite ranges on the north and south of the ferriferous belt of the azoic system." (*l. c.*, pp. 50-69.)*

Dr. J. J. Bigsby regarded the granite as igneous, and taught that the metamorphic rocks had been "upheaved and altered by the intrusion of igneous rocks in instances innumerable."† Professor Whitney, in his "Metallic Wealth of the United States," (Philadelphia, 1854,) again advocated the igneous origin of the iron ores in this district, as well as in some other localities.‡

In 1854 there was published by Henry R. Schoolcraft, in Philadelphia, a work entitled "Summary Narrative of an Exploratory Expedition to the Sources of the Mississippi River, in 1820: resumed and completed by the Discovery of its Origin in Itasca Lake, in 1832. By Authority of the United States. With Appendices, comprising the Original Report on the Copper Mines of Lake Superior, and Observations on the Geology of the Lake Basins and the Summit of the Mississippi; together with all the Official Reports and Scientific Papers of both Expeditions." As giving us an insight into the early knowledge of the geology of the southern shore of Lake Superior, this work naturally should be of great value, especially as it purports to contain the original scientific reports. In the Preface we learn that he brings the subject down to the date of publication in some respects, and by comparing the work with the original, published in 1821, we find that he gives discoveries as if made by himself in 1820 which were not made until at least nearly twenty-five years later. This insertion in the body of the text may perhaps be pardoned, in the light of the Preface; but when it comes to publishing official documents with their original date and official signature, but with a "tinkered" body, we object. We cannot therefore credit Mr. Schoolcraft with the discovery of the iron ore of the Marquette district in 1820, although any one reading this work would suppose that he discovered it. It represents to us simply what he wished, in 1854, others should think he had known and written in 1820. This also applies in part to his reports on the Copper district, and we shall not mention the book further.

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* Am. Jour. Sci., (2,) XVII. 11-38, 1854; XXII. 305-314.

† Edinburgh New Phil. Jour., 1852, LIII. 55-62.

‡ Pp. 37, 429-437, 477, 478. See also Proc. Am. Assoc. Adv. Sci., 1855, 209-216; Mining Magazine, (New York, 1856,) VII. 67-73; Am. Jour. Sci., (2,) 1856, XXII. 38-44.

In 1854 was also published a description of this and the Copper region by Fr. C. L. Koch.* The trap and granite were regarded as eruptive, and it was thought that the quartz rock (quartzite) may probably be so. The schists are supposed to have been metamorphosed through the agency of igneous masses. The iron rocks he would consider as upheaved from great depths, or else to have suffered great metamorphism by the influence of igneous masses. That they (the iron rocks) may be simply the quartz rock impregnated with oxide of iron is thought probable.

In 1855 and 1856 two papers on this and the Copper district were published by Prof. L. E. Rivot.† As we understand his work, it would seem that he regarded all the rocks from Sault St. Marie to the Ontonagon River as of sedimentary origin, and of the same geological age, whose differences were entirely owing to peculiar metamorphism, or its absence, as the case might be. The sandstones were in general, in the Marquette district, of prior deposition to the other rocks in the places in which they are now to be found. The traps and their associated schists, which originally formed the base of the sandstone, had been locally changed and pushed up, dislocating the surrounding sandstones. The granites and sienites were regarded as probably the products of the last stage of metamorphism, although they were eruptive in their present position. The "diorites" of the Marquette district were considered to be the same, in age and general characters, as the traps in the Copper district, all being interstratified with the sedimentary rocks with which they are associated, and into which they gradually pass. The differences between them and their associated rocks were owing to the degree and manner of the metamorphism. The whole formation from the Sault to the Ontonagon was regarded as Potsdam, being overlaid by the magnesian limestone.

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* Studien des Gott. Vereins Bergm. Freunde, VI. 1–248.

† Annales des Mines, (5,) VII. 173–328, X. 365–474.

Prof. J. P. Lesley, in his "Iron Manufacturers' Guide," (New York, 1859,) opposes the view of Professor Whitney, that the iron ores of Lake Superior or of any other region are eruptive. It seems strange that a geologist and mining engineer of his reputation should fall into the errors that he has, in interpreting the latter's work. After quoting Professor Whitney's remarks on *mineral veins*, he says: "The first theory which Mr. Whitney so summarily dismisses as opposed to all known facts, is in certain principal localities the only one which apparently embraces all the facts. The so-called *veins* of specular and magnetic ore in Northern New York, New Jersey, and Missouri are of this class, and when Mr. Whitney says that 'the mountain masses of Missouri have pre-eminently an eruptive character, and are associated with rocks which have always been considered as of unmistakably eruptive origin,' we must interpret the expression by the preceding and succeeding paragraphs as the judgment of the past, and not his own, saying that the specular and magnetic ores of Lake Superior, New York, and Scandinavia fall into the same category, and yet are not true veins, but 'slaty beds impregnated with peroxide of iron, ... exhibiting the appearance of a secondary action having taken place since their original formation.'" (*l. c.*, pp. 354, 355.)

On referring to Professor Whitney's work, it can be readily seen that the remarks on *mineral veins* by Professor Whitney have nothing whatsoever to do with the above quoted iron-ore deposits, which are not *mineral veins* in any sense, and were distinctly separated from them by him. The expression, "slaty beds, impregnated with peroxide of iron," was used in reference to the mine of Hessel, Norway, while the statement, "exhibiting the appearance of a secondary action having taken place since their original formation," was applied to the azoic ores of New York, and is copied by Professor Lesley on page 357 of his work in its proper connection. It will thus be seen that specials have been transformed by Professor Lesley into generals, entirely out of their original use; and remarks about one thing are said to have been made about another.

After copying several pages from Professor Whitney's "Metallic Wealth," he writes: "It appears from the foregoing that Mr. Whitney accepts both the eruptive and the sedimentary theories of the formation of the primary iron ores, and applies the former to unknown, invisible masses, antecedent to and now deeply buried under all, even the oldest rocks which appear upon the present surface; masses of far greater size and depth than the greatest yet discovered, proportionate to the greater scale of all volcanic action in that pre-azoic day, and offering their sides and tops to such erosion and solution as would of course happen in such unsettled times, and be sufficient for producing the vast sediments of iron which have been taken for volcanic outbursts of the molten metal. But there is a fatal difficulty in the way of this hypothesis. These ore-beds are not *breccias*. Deposits of the kind imagined would be *conglomeritic*; blocks of pig-iron would be seen scattered through strata of granite." Here, again, he has entirely misunderstood Professor Whitney's views, which were that the great masses of ore in the Lake Superior district were eruptive where they now are, and were never sedimentary deposits, while associated with and derived from them are the *brecciated* and *conglomeritic* ores, as well as other sedimentary beds. If it is necessary, the "pig-iron" can doubtless be found at Ovifak, Disko, in the basalt (*l. c.*, pp. 333-335, 353-361, 480-489).

In 1861 the rocks of the Marquette iron district were referred to the Huronian system by Dr. T. Sterry Hunt, on the authority of Mr. Alexander Murray.* Dr. Hunt regarded the Huronian then as the equivalent of the Cambrian of the European geologists.

Dr. Dana† states concerning the iron ore of Michigan and elsewhere: "Their alternation with chloritic and other schists and gneissoid rocks shows that they are metamorphic as well as the schists." The same statement is made in the edition of 1874 (p. 74), and doubt is expressed as to whether they belong to the Laurentian or Huronian (pp. 151, 152, 159, 160). Since the above was written the third edition of the Manual has been published, but this affirms as strongly as ever that the iron ore is in stratified sedimentary beds, and that it is distinctly interstratified with the schists.

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* Am. Jour. Sci., 1861, (2,) XXXI. 392-414; Canadian Nat. and Geol., 1861, VI. 81-105, VII. 127.

† Manual of Geology, 1862, pp. 83, 84.

Later, Dr. J. J. Bigsby, while considering the Huronian as distinct from the Cambrian, still referred the rocks of this district to the Huronian.*

In the "Geology of Canada," 1863, these rocks are taken as Huronian (p. 66). The rock at Presque Isle was classed as a sedimentary serpentine belonging to this formation by Dr. Hunt (pp. 472, 595); taking his analysis from Professor Whitney's work,† who regarded it as closely related to serpentine.

Dr. Hunt states also that the great beds of red hematite are stratified (p. 596), and he considers their deposition as proof of the presence of vast amounts of organic matter at that day (p. 573).

Dr. J. P. Kimball, under date of December 19, 1864,‡ remarks: "My own observations in the Iron region impressing me with the indigenous character of the larger masses of diorite and granite represented within the defined area of the metamorphic strata, and their entire distinctness from intrusive dikes or erupted masses, and concurring in the recognition of these strata by Mr. Murray as Huronian, I am disposed to regard the entire region as of metamorphic character, all of whose larger masses of crystalline rocks are indigenous, and to be divisible into the two formations, Laurentian and Huronian: the former formation probably forming the surface of the areas known as the granite ranges, while the latter probably occupies, with minor deviations, the limits laid down for the crystalline schists comprehended under the name Azoic." (*l. c.*, p. 293.) "Possessing the same stratigraphical conditions as the schistose rocks, while many varieties of them are represented in the schists by their exact counterpart as to composition, the crystalline Huronian rocks must be regarded as essentially metamorphic, while in a comprehensive view of the whole series it is seen that together with variable conditions of deposit, it indicates variable degrees of local metamorphism. Plentiful evidence exists of the blending of a rock of one character into that of the other, or the continuity between crystallized and schistose beds. . . . . Besides the indigenous crystalline rocks distributed throughout the Huronian series, exotic or intrusive crystalline rocks are met with, but only in the form of dikes, and limited to a narrow distribution." (*l. c.*, p. 295.) "It may not be inappropriate to suggest the probability that the larger and more persistent bodies of greenstone bearing approximately east and west — that is, conformably with the axes of the folds which constitute a regular system of flexures coextensive with the distribution of the Huronian series in the vicinity of Marquette, are, in reality, indigenous greenstone, and a portion of the development of the diorite upon which repose the upper members of the series, and which, as will hereafter be shown, is uncovered along most of the ridges of the region." (*l. c.*, p. 296.) "The position of the beds of specular iron ore has already been stated to be at the top of the Huronian series, ... interstratified with talcose and argillaceous schists. Sharing the plications of the entire series, these specular schists, as they may properly be called, are accordingly folded into synclinal basins and anticlinal crests." (*l. c.*, p. 299.) "It has been shown that the iron ores of the Huronian series in Michigan are essentially schists and heavy-bedded strata, in which none of the phenomena of aqueous deposits formed by precipitation from water on the one hand, or by detrital accumulation on the other, are wanting. They exhibit not only stratification, anticlinal and synclinal folds, but are invariably traversed by systems of joints, and at many points exhibit a perfect slaty cleavage. The intimate connection between the greenstones, hornblende rocks, and aluminous and magnesian silicated schists of the ferriferous series, has already been indicated in general terms, these rocks not only alternating with, but passing into each other." (*l. c.*, p. 302.) "Chemical reactions in crystalline sediments resulting from the disintegration of crystalline silicated rocks, and operated upon by carbonated waters, are amply capable to have produced the lithological conditions of augitic rocks, clay-slates, schalstone, and other schists, together with the oxidized ores of iron intercalated with greenstone among the ancient crystalline rocks of North America as well as of Europe. . . . . From a stratigraphical point of view, while evidence is elsewhere often obscure, the Huronian greenstone, schists, and iron ores of Northern Michigan, in the absence of close attention to their special chemical conditions, exhibit sedimentary and metamorphic phenomena adequate to render quite untenable, it is believed, the theory of the exotic character of any portion of them." (*l. c.*, p. 303.) The granite is also regarded as indigenous by Dr. Kimball.

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* Quart. Jour. Geol. Soc., 1863, XIX. 36 – 52.

† Am. Jour. Sci.,, (2,) XXVIII. 18, 1859.

‡ Am. Jour. Sci., (2,) 1865, XXIX., 290 – 303.

Mr. J. W. Foster, in 1865,* states: "The Iron Region consists of an assemblage of rocks of various kinds, such as argillite, talcose, chlorite, and hornblende schists, quartzites, and occasionally dolomites, all of which are supposed to be of metamorphic origin, intermingled with rocks whose igneous origin can hardly be doubted, consisting of the various compounds of feldspar and hornblende, forming greenstone or dolorite; or where silica abounds, forming syenite; or serpentine where magnesia is in excess. . . . . It may be stated as a general rule, that the great iron deposits of the district occur in close proximity to the igneous rocks, mainly greenstone. This rock forms nearly all of the prominent peaks of the region, not in continuous ranges, but in a succession of dome-shaped knobs, while the iron ores repose upon their sides, or dip beneath their bases, so that the greenstone appears rather in the form of intercalated beds than as wedge-shaped masses. The whole region has been subjected to a powerful denudation, and the greenstone, being the more unyielding rock, has been left in the form of knobs, or of ill-defined ridges. I cannot recall an instance where it forms a true axis of elevation." (*l. c.*, p. 9.) The limonitic ores (soft hematites of the miners) are regarded by him and by Dr. Kimball as formed by the decomposition of the hematite ores *in situ* (*l. c.*, pp. 24, 81). Dr. Kimball also states in this report (p. 87): "Regarding the bodies of specular iron ores and earthy red hæmatites of the Marquette Region as of combined aqueous and metamorphic origin; and, conditional to this view, apprehending the stratigraphic arrangement of the general system of aluminous and magnesian silicated schists, among which these beds are intercalated, generally regular and constant as it is, the topography of the country affords tangible data for tracing the hidden conditions of ore beds, and their relation to outcropping rocks. The region is traversed by a series of folds, or undulations, of the entire series of rocks, which impart to the surface its contour, modified only through subsequent agencies of denudation. Thus the crests of the undulations (*i. e.* the ridges and hills), originally overlaid by beds of iron ore, which in its purer conditions readily yielded to the abrasion of glacial action, were worn down and commonly stripped to the underlying rock."

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* Geology and Metallurgy of the Iron Ores of Lake Superior, by J. W. Foster and J. P. Kimball, New York.

In "Coal, Iron, and Oil, or the Practical American Miner," etc., by S. H. Daddow and Benjamin Bannan, published in 1866, a decidedly original view of the origin of the iron ores and their associated rocks, as well as of the placer gold of California, is given (pp. 532, 533, 546 – 550). All are thought to have been formed by volcanic action. "We are aware that all our sedimentary rocks were formed in water, and that the materials forming them are the results of volcanic action. The logical sequence is, that those volcanoes either existed in water, or vented their lava into it. Metals are always heavier than their matrix, or the earthy strata in which they are found; thus, if the lava contained a large amount of metal, it would be the first to be precipitated to the bottom of the water into which the lava was vented. The lava would not run in a solid stream from the crater, and solidify as a stratum in the water, but the moment it touched the adverse element it would be shivered to atoms, and thrown back into the atmosphere with the steam it would create, and the lighter portions would naturally arise in dust and ashes, and be carried by winds and waves and tides to remote localities, while the heavier materials would be precipitated in the vicinity in the order of their density. . . . . We may refer most of our great Azoic beds of magnetic and specular ores and red oxides of iron to this cause, and their formation to these agencies. We may also refer the alluvial or drift gold in the 'placers' of California and the 'diggings' of Australia to the same causes." (*l. c.*, p. 533.)

It is such theories as this, and many others touched upon in this paper, that give the "funny side" to our work, and serve to enliven the tedium of it; otherwise they would not be worthy of preservation. They stand as the caricatures of science, although they were evidently sober realities to their authors.

A series of papers was published by Dr. Hermann Credner in 1868–70, the titles of which will be given in the literature at the end of this work. He divides the formations as follows: the gneiss-granite, or Laurentian formation, and the limestone-quartzite-iron-stone, or Huronian formation. The latter is said to unconformably overlie the former, but the evidence, so far as given, is derived from the dip and strike of the lamination, and not from observation of the kind and manner of their contact. The diorites, iron ores, and all their associated rocks, except a few, are regarded as interbedded formations. The iron ore is supposed to have all originally been magnetite, and in part changed since to hematite and limonite. Near Marquette certain diorites were seen by him to be eruptive; therefore they were taken to be of different age from the interbedded diorites associated with the iron ore, and younger than the Huronian.

In Prof. A. Winchell's Report of Progress of the Geological Survey for 1870 we find the following remark: "The rich masses of magnetic and hematitic ores of iron are found not to be those erupted outbursts which the older geologists were inclined to regard them. They are simply constituents of the system of sedimentary deposits which make up the Huronian System of Michigan. The diorites of the region appear to be equally of sedimentary origin, and are found strictly interstratified with chloritic, siliceous, talcose, argillaceous, micaceous, and hematitic schists, in the foldings and convolutions to which these masses of ancient strata have been subjected." (*l. c.*, pp. 26, 27.)

In 1873 the Report of Major T. B. Brooks on the Iron districts of Michigan was published, with various accompanying documents by Messrs. Julien, Wright, Houghton, Lawton, and others.* Mr. Brooks refers the date of the discovery of the iron ore to 1844, by Mr. William A. Burt and party, but the first official documents giving an account of the ore seem to have been the reports of Burt and Hubbard for 1845,† referred to in the early portion of this paper. Besides the sandstone, the formations of this district are divided by Mr. Brooks as follows: "*The Iron-bearing Rocks*, corresponding, it is assumed, with the Huronian system of Canada, consist of a series of extensively folded beds of diorite, quartzite, chloritic schists, clay, and mica slates, and graphitic shales, among which are intercalated extensive beds of several varieties of iron ore. . . . . *The Granitic Rocks*, which so far have produced no useful minerals, and which are believed to be the equivalents of the Laurentian of Canada." (*l. c.*, p. 66.)

As we shall have largely to deal with Mr. Brooks's work hereafter, we shall quote quite fully from it. "Useful minerals which occur in beds, like the iron ores of Lake Superior, will usually be overlaid and underlaid by rocks having different characters, and which maintain those characters for considerable distances. Next to finding the ore itself, it is desirable to find the hanging or footwall rock. Whoever identifies the upper quartzite in the Marquette region, or the upper marble in the Menominee region, has a sure key to the discovery of any ore that may exist in the vicinity. With few exceptions, all the rocks in the region we are describing are stratified,—that is, arranged in more or less regular beds or layers, which are sometimes horizontal, but usually highly inclined. This stratification, or *bedding*, is generally indicated by a difference in color of the several layers, oftentimes by a difference in the material itself, but occasionally the only difference is in the texture or size and arrangement of the minerals making up the rock. . . . . In general, a *striped rock*, whether the stripes be broad or narrow, plain or obscure, on fresh fracture or weathered surface, is a stratified rock."

We would invite Mr. Brooks to inspect the volcanic rhyolites, many of the felsites that are known to be eruptive, as well as many of the furnace slags to be seen in the Marquette district. "Sometimes the power which produced the *folds* seemed greater than the rocks could bear, and cracks or breaks, and *faults* or throws, are the result, though these are not numerous in the Lake Superior region. Cracks so produced, and filled with material other than that constituting the adjacent rocks, are called *dykes;* or, if the material be crystalline and metalliferous, *veins.* As iron ore in workable quantities does not occur in this form in this region, vein phenomena will not be considered here." Of the Huronian series "the prevailing rock is a greenstone, or diorite, in which, like the copper traps, the bedding is usually obscure; but the intercalated schists and slates, which usually bear strong marks of stratification, make it usually not difficult to determine the dip of the beds at any point. . . . Descending to the oldest or bottom rocks of the Lake Superior country, the granites and associated beds (*Laurentian*), we find the bedding indications still more obscure, and often entirely wanting." (*l. c.*, pp. 74, 75, 76.)

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* Geological Survey of Michigan, I. 1–319; II. 298 pp.

† I. 13, 14; II. 235–238.

"In subdividing the Huronian or iron-bearing series which we have particularly to study, the rocks have been grouped (1) *lithologically, i. e.*, according to their mineral composition, and (2) *stratigraphically, i. e.*, according to relative age. As this system was first described and named by the Canadian geologists, their names have been employed as far as possible in the body of this report; the identity in composition of many of our rocks with theirs, having been established by an examination of a large number of Marquette specimens by Dr. T. Sterry Hunt." (*l. c.*, p. 82.) "The several beds or layers of the Huronian system, as developed in the Marquette region, are numbered upwards from I. to XIX. . . . . I., II., III., IV., are composed of beds of siliceous ferruginous schist, alternating with chloritic schists and diorites, the relations of which have not been fully made out; V. is a quartzite, sometimes containing marble and beds of argillite and novaculite; VI., VIII. and X. are siliceous ferruginous schists; VII., IX. and XI. are dioritic rocks, varying much in character; XIII. is the bed which contains all the rich specular and magnetic ore, associated with mixed ore and magnesian schist; XIV. is a quartzite, often conglomeritic; XV. is argillite or clay slate; XVI. is uncertain, it contains some soft hematite; XVII. is anthophyllitic schist, containing iron and manganese; XVIII. is doubtful; XIX. is mica schist, containing staurolite, andalusite, and garnets. This classification, it will be borne in mind, applies only to the Marquette region. . . . . These beds appear to be metamorphosed sedimentary strata, having many folds or corrugations, thereby forming in the Marquette region an irregular trough or basin. . . . . While some of the beds present lithological characters so constant, that they can be identified wherever seen, others undergo great changes. Marble passes into quartzite, which in turn graduates into novaculite; diorites, almost porphyritic, are the equivalents of soft magnesian schists." (*l. c.*, pp. 83, 84.)

The "soft hematites" are thought to result, perhaps, from the decomposition of a "limonitic siliceous schist," with which they are associated. "It is not at all improbable that this change may have been brought about by the alkaline waters of former thermal springs." (*l. c.*, pp. 90, 91.)

The "diorites" are said to graduate from a heavy, tough, black variety into a soft, light-colored rock, resembling chloritic schist more than anything else, and called by him dioritic schist. "The bedding of these rocks is generally obscure, and in the granular varieties entirely wanting. It is usually only after a full study of the rock in mass, and after its relations with the under and overlaying beds are fully made out, that one becomes convinced, whatever its origin, it presents in mass precisely the same phenomenon, as regards stratification, as do the accompanying schists and quartzites. . . . . No reference is here made to the false stratification or joints, which are numerous and interesting, but which unfortunately, for want of space, can receive no other attention here than to warn the observer against mistaking *joint* planes for *bedding* planes, which is sometimos done, even by experienced observers." (*l. c.*, pp. 102, 103.) He also states that in no case has he abserved a Huronian diorite in the Marquette district that does not conform "with the schistose and slaty strata with which they are associated." (*l. c.*, p. 156.)

The rocks associated with the hard ores and "diorites" are called "magnesian schists (mostly chloritic)." He says regarding them: "It would be difficult for a skilled lithologist, and impossible for me, to draw the line between the chloritic schists here considered and the dioritic schists." Regarding the chloritic schist at one locality associated with "specular slate ore," it is stated: "Prof. Pumpelly has suggested that one may be a pseudomorph after the other. In this connection it may be remarked that no gradual transition of one into the other was observed, the division planes being in each instance sharply defined." (*l. c.*, pp. 104, 105.)

Regarding the connections of the ore in the Barnum mine with that in the Lake Superior mine, he writes: "It shows that such formations are not vein or dyke-line deposits, but true stratified beds, like the rocks by which they are enclosed. Their structure is therefore essentially the same as the coal, limestone, sandstone, and slate-beds, which are regarded as sedimentary deposits from water, subsequently more or less altered by heat, pressure, and chemical waters acting during immense periods of time. The Lake Superior-Barnum deposit evidently has a *bottom*, which will be reached within a period, of which it is worth while for the present generation to take some heed. . . . . The time may come when, having worked out the steep, upturned edges of the basins, and the flatter or deeper portions of the deposit are reached, ore properties will be valued somewhat according to the number of acres *underlaid by ore*, as coal now is. Passing to the east portion of the Lake Superior mine, I confess myself unable to give any intelligent hypothesis of its structure. . . . . There seems to have been such a gathering together, crumpling, squeezing, and breaking of the strata, as nearly to obliterate the stratification. . . . . The remarkable features are the great masses of light grayish-green chloritic schist, having a vertical east and west cleavage, no discernible bedding planes, and holding small lenticular masses of specular ore, which conform in their strike and dip with this cleavage, and which seem to have no structural connection with the main deposits. They appear like dykes of ore, squeezed out of the parent mass, which we may suppose to have been in a comparatively plastic state when the folding took place; or they may have been small beds, contained originally in the chloritic schist, and brought to their present form and position by the same causes, which produce the cleavage in the schist. . . . . The peculiar nature of the hanging wall of the Lake Superior mine deserves further notice. Instead of the quartzite, which we have hitherto found overlying all the deposits of rich ore, we have here a magnesian schist very similar to, if not identical with, that already mentioned as being associated with the ore." (*l. c.*, pp. 138 – 140.)

"All the Huronian rocks north, east, and south from the Jackson mine are below, or *older than the ore formation* (XIII)., and all the rocks to the westward and inside of the ore-basin are *younger*, hence above it." (*l. c.*, p. 143.) "The iron-bearing or Huronian series of rocks are stratified beds, the principal ore formation being overlaid by a quartzite XIV., and underlaid by a diorite, or greenstone XI. This ore formation is made up, first, of pure ore; second, of 'mixed ore' (*i. e.* banded jasper and ore); and third, a soft, greenish schistose, or slaty rock (magnesian), which occurs in lens-shaped beds which alternate with ore, thus often dividing the formation into two or more beds of ore, separated by rock. Usually the beds of both ore and rock thin out as they are followed in the direction of the strike from a centre of maximum thickness, producing irregular, lentiform masses. Since their original deposition, if we may assume they were laid down under water, the whole series, including the iron beds, have been bent, folded, and corrugated into irregular troughs, basins, and domes, which often present at the surface their upturned edges of pure ore, standing nearly vertical." (*l. c.*, p. 245.) "The trouble is to find out when a pit is exhausted, — it is so common to break through a thin layer of rock, and find a bed of workable ore behind it." (*l. c.*, p. 262.)

The proof advanced by Mr. Brooks to show the unconformability of the so-called Huronian to the so-called Laurentian, and the greater age of the latter, is in substance this: the foliation of the latter was found in two places to dip in a different direction from that of the lamination of the "Huronian" schists near by (*l. c.*, pp. 126, 156). His proof then rests entirely on the hypothesis that these planes are the original bedding planes of these rocks. This hypothesis again assumes that all are sedimentary rocks, — a point still in doubt at the time of his writing, as regarded one of the rocks at least. It is to be noticed that the two formations were not seen in contact. He also remarks (*l. c.*, p. 156): "The non-conformability is further proven by the fact that the Laurentian generally abounds in dikes of granite and diorite, which are almost entirely absent from the Huronian." Concerning certain rocks in the Menominee district we find this acknowledgment: "It must be admitted, however, that the lithological affinities of this series of rocks of the north belt are decidedly Laurentian, rather than Huronian. The gneiss and granite outcrop above described, may be almost regarded as a typical Laurentian rock in its appearance. If future investigations prove them to be Laurentian, a very troublesome structural problem would be presented here, as we would have Laurentian rocks conformably *overlying* beds, unmistakably Huronian. There seem to be fewer difficulties in supposing that the Huronian rocks of the Menominee region embrace lithological families not, so far, found represented in the equivalent series in the Marquette region." (*l. c.*, p. 175.)

Part III. of the above-mentioned work is devoted to the report of Dr. C. Rominger. We take some extracts from this: "A locality on the shore, two miles south of Marquette, where the sandstones in their contact with the Huronian Quartzites can be seen, has been previously described in Foster and Whitney's report on the Lake Superior district. We find here vertically erected white Quartzite beds of the Huronian group projecting into the lake, which have preserved their granular sandstone structure, and are distinctly ripple-marked. They are surrounded by brown sandstone and conglomerate ledges, horizontally abutting against them. The sandstones, which are of very irregular discordant stratification, closely adapt themselves to all inequalities of the cliffs, which exhibit under the sandstone covering a rounded water-worn surface, indicating their long exposure before they were enveloped by the sandstones." (*l. c.*, p. 90.)

Of Presque Isle he says: "This landspur is formed by a protrusion of peculiar rock-masses, differing considerably from the rock-beds of the Huronian group in the vicinity. Lowest is a black, unstratified, semi-crystalline magnesian rock, resembling a half-decomposed basalt or a highly ferruginous serpentine. It forms considerable cliffs at the north end of the spur; — more to the south we find it overlaid by a more light-colored, once-stratified rock, which is involved in the upheaval, with its ledges bent and broken up in great confusion." He regards this as a dolomite. It is the same rock that Houghton considered to be sedimentary, and Foster and Whitney as a volcanic ash. "On the south portion of Presque Isle this dolomite is inconformably overlaid by a conglomerate and succeeding sandstone layers, which are identical with the sandstones of the Marquette quarries. The sandstone strata some distance off from the protrusive rocks are nearly horizontal.* In immediate contact with them they have a considerable dip, corresponding to the convexity of the underlying surface. It is possible that the strata were slightly uplifted after their deposition, but I am more inclined to explain the existing dip as an adaptation of the sediments to the surface on which they were deposited. The conglomerate beds at the base are five feet thick, and contain numerous fragments of the underlying dolomitic rock and of their enclosed Jaspery minerals." (*l. c.*, pp. 90, 92.) He regards certain rocks at Light-house Point and Picnic Island as intrusive diorites, giving evidence therefor, and also remarks: "The Diorites *interstratified* with the Huronian schistose rocks in the environs of Marquette, and particularly at the Light-house point, are of an evidently *intrusive* character." (*l. c.*, p. 93.) The italics are ours, as we are anxious to know how the same rock can be interstratified and intrusive at the same point.

In a paper by Prof. J. S. Newberry, on "The Iron Resources of the United States," † we find the following statement: "On Lake Superior it is now easy to see that the ore-beds were once horizontal strata, deposited in conformity with many other stratified sediments, but they are folded and broken in such a way that their true nature was for a long while misunderstood. Like the magnetic ores of the Alleghany belt, they were once considered eruptive; but the progress of modern science has shown that all the so-called Eozoic iron ores are simply metamorphosed strata, once deposited horizontally like the sheets of iron ore now found in the unchanged Palæozoic rocks, — such as the Clinton ore and the 'black-band' and 'clay ironstone' of the Coal Measures."

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* May we be pardoned for saying that, according to Messrs. Pumpelly and Brooks (see quotations from them on the Copper district), this is proof positive that the Potsdam sandstones abut unconformably against the *Presque-islian series*, which must then have formed an island in the Potsdam sea.

† International Review, 1875, I. 754 – 780.

Col. Chas. Whittlesey,* in 1875, opposed the idea that the granitic region was Laurentian, but regarded the rocks as eruptive. He accepted the view of the Huronian age of the schists, however.

In the Transactions of the Wisconsin Academy of Sciences, Arts, and Letters,† Mr. E. T. Sweet calls attention to the unconformability of the Laurentian and Huronian with one another at Penokie Gap, Wisconsin. It will be seen, however, by reference to the paper, that the absolute contact was not observed.

In 1875 Mr. Brooks again took up the question of the granites in the Menomonee district, which, according to him,‡ overlie the iron-bearing rocks of that region. In order to solve the difficulty he assumes that they are the youngest Huronian rocks (Formation XX.), and immediately underlie the copper-bearing series.§

The only reason, so far as we can learn from his paper and the original observation quoted by us (*ante*, page 22), for this supposition is, that, while they are lithologically identical with the "Laurentian" rocks, he can dispose of them best by placing them as the youngest of the Huronian rocks. Furthermore, unless he did this, the "Laurentian" would be younger than the "Huronian" at this point, a conclusion that would vitiate his former statements. He therefore deliberately violates the lithological laws on which his work rests, and makes it simply a question of where each rock will fit into his system the best.

From Dr. T. Sterry Hunt's "Azoic Rocks,"‖ we learn that from hand specimens sent him by Mr. Brooks he established the presence of the Montalban series, as well as the Laurentian and Huronian (*l. c.*, p.

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* Proc. Am. Assoc. Adv. Sci., 1875, XXIV. 60-72.

† Vol. III., 1875-76, pp. 40-55.

‡ Mich. Geol. Survey, I. 175.

§ Am. Jour. Sci., 1876, (3,) XI. 206-211.

‖ Sec. Geol. Survey of Penn. E. Part I.

223). The greenstones of the Huronian were also said to be indigenous, i. e. rocks formed *in situ* from sediments (*l. c.*, p. 221).

We next come to the report of Mr. Charles E. Wright,* in which we are informed that all the granites of the Upper Peninsula and Wisconsin that have been examined by the writer are metamorphic. This view is based upon microscopic characters, and we should object, *in toto*, to the premise. He also states: "Some objections were made last summer (1876) by Dr. Rominger as to the non-conformability of our so-called Laurentian and Huronian series, on the ground that he had observed in several instances 'a perfect conformability of these supposed distinct series.' It seems perfectly natural to me that this should often occur; and were I to find ninety-nine places where an apparent conformability existed, and only one of decided non-conformability, the latter would, in my estimation, outweigh all the former." (*l. c.*, p. 11.) He states that a perfect case of nonconformability exists at "Penoka Gap," Wisconsin, to which we have before referred; but if we remember correctly Mr. Wright's personal statement to us, neither was the junction seen nor the kind of junction known that the two made with each other. It is too fast to assume, as has been done by Messrs. Brooks, Irving, and Wright, that the strike and dip of a foliated rock is the strike and dip of its stratification. This is especially the case when the view that they were ever stratified is still a disputed point.

Of the Huronian series the quartzite is said to show frequent ripple-marks. The soft hematite is thought to have been formed as follows: "In these mines it appears that the finely divided silica has been more or less dissolved out by alkaline thermal water, leaving the iron oxide and other bases behind." (*l. c.*, p. 15.) The iron ore is regarded as sedimentary, and Brooks's geological ideas are closely followed.

He sustains Mr. Brooks's division of the granites into Laurentian and Huronian (Formation XX.), by the statement that he finds salt cubes in the fluidal cavities of the latter, but not in the former.

Lastly, we have Mr. W. O. Crosby's paper, "On a Possible Origin of Petrosiliceous Rocks,"† in which he thinks it probable that the jasper and its associated iron ores are the representatives of a deep-sea deposit, like the "red clay" discovered by the Challenger expedition, below the depth of 2500 fathoms.

It may not be amiss to incidentally refer to the treatise of Mr.

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* First Annual Report of the Commissioner of Mineral Statistics for the State of Michigan, 1879.

† Proc. Bost. Soc. Nat. Hist., 1879, XX. 160-169.

D. C. Davies on Metalliferous Minerals and Mining.* It would be difficult to imagine a description or a section so at variance with the facts as the ones that he gives on pages 274 and 275. We feel that all geologists who have been in this region will be surprised to be informed that "lingulæ are abundant in the overlying sandstone." On page 149 he has represented the copper-bearing rocks and sandstone (Potsdam) as resting directly upon, and at a steep angle dipping away in both directions from, the iron-bearing rocks; also, the western copper rocks as dipping east, and resting upon a similar set of iron rocks. It is to be hoped that the rest of his book is not so erroneous as this.

Historical Summary.

In general, then, in looking over the views advocated by past observers, we find, in brief, the following opinions held.

The rocks† of this district were all taken as azoic by Foster and Whitney, and not considered to be capable of subdivision into geological periods. We must also notice that Prof. H. D. Rogers regarded them as of primal or Potsdam age. On the other hand, we find that this formation is divided by Murray, Hunt, Kimball, Winchell, Credner, Brooks, and Wright into the Huronian and Laurentian. This division is based upon lithological characters, and an unconformability said to exist between the two. Rivot considered the whole as Potsdam.

The granite is regarded as an eruptive rock by Foster and Whitney, Bigsby, and Whittlesey; and as of sedimentary origin by Rivot, Kimball, Brooks, Hunt, and Wright. These latter, with Credner, take it as being older than the schistose rocks associated with the iron ores, and, excepting Rivot, with its accompanying gneissoid rocks composing the Laurentian formation. Foster and Whitney and S. W. Hill regarded the granite as younger than, and eruptive in, the schists.

The gneisses and schists were taken by all the observers as being of sedimentary origin, except possibly Whittlesey, whose language is as obscure as the formations about which he writes.

The metamorphism of the schists is supposed by Hubbard, Rivot, Kimball, Hunt, Brooks, and Wright to be occasioned by chemical agencies accompanied, as part thought, by galvanism. Foster and Whitney and Bigsby considered that the metamorphism was brought about by the presence of eruptive rocks, and their accompanying chemical agencies. Foster and Whitney regarded the "diorites" of this region as eruptive rocks, but Rivot, Kimball, Hunt, Winchell, Credner, Brooks, and Wright, as sedimentary ones and interstratified with the schists.

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* London: Crosby, Lockwood, & Co., 1880.

† Excepting the sandstone, which will be spoken of in our remarks on the Copper district.

The iron ores are regarded as all of sedimentary origin by Foster, Kimball, Dana, Hunt, Winchell, Credner, Brooks, Newberry, and Wright, but are believed for the most part to be of eruptive origin by Whitney, and by Foster and Whitney. These ores were said to be in the upper portion of the Huronian series by Kimball, Brooks, and Wright, with the "diorites" underlying them.

It will thus be seen that, while Foster and Whitney regarded certain of the rocks in the "Huronian" as eruptive, Hubbard, Rivot, Kimball, Hunt, Credner, Brooks, and Wright regarded all, with a few slight exceptions, as sedimentary; and Houghton, Hubbard, Locke, Kimball, Rivot, and Brooks teach that they pass by gradual transition into one another.

The most important points, then, about which there has been or is difference of opinion, are the age and relation of the granite and schists, the origin of the diorites and iron ores, the passage of one rock into another, and the presence or absence of eruptive rocks. These and other questions relating to this district admit in many cases of no middle ground; one or the other party must be mistaken in their observations or conclusions, or both. All these questions lie closely to the fundamental propositions of geology; they reach to the superstructure of the science.

Methods of Observation.

The object of the writer in visiting the Iron district was to clear up some of the preceding mooted points in the geology of that region, if possible, especially the origin of the iron ores and their relations to the country rock.

From our personal experience in both regions, we should hold that the ordinary methods of geological research which are employed in the study of the comparatively undisturbed and unaltered sedimentary rocks of the Mississippi Valley are not sufficiently accurate for our purpose in the Lake Superior district, where the rocks are foliated, disturbed, and of mixed eruptive and sedimentary origin. Stratigraphical laws that hold good in the former region do not in the latter, especially when it is sought to connect together two rocks of unlike character, or when the nature and origin of either or both is a point of dispute. In this disturbed district the presence of a rock in one place will hardly prove the presence of the same one in another, except by direct connection, even if the two do look alike, especially if that sameness is questioned. If the two rocks are identical in structure and composition, nothing but the proof of direct, absolute continuity places the question of their identity beyond dispute here, especially if we have any reason to suspect the eruptive origin of one or both of them. Lamination, banding, joint planes, cleavage, pseudo-stratification, and fluidal structure, are not to be taken as proof of stratification in doubtful rocks. The very origin and nature of all, except, perhaps, the true fluidal (not pseudo-fluidal) structure, are yet open questions. Until it is proved that they are confined to one class of rocks, it is unsafe to use them to prove that any questionable rock belongs to that class. Doubly so is it when it is well known that they are not so confined. If they are not to be used to determine the sedimentary origin of a rock, in like manner the dip and strike of such structures ought not to be taken to prove order of superposition, conformability, or non-conformability, especially as this proceeds upon the supposition that both rocks in question are sedimentary. That a sedimentary rock is horizontal, or has a certain dip at one place, is not to be taken as proof of what its position must be in another locality, unless the conditions remain the same.

It may be said that every rock carries in itself, or in its relations to its associates, or both, its history, more or less complete. In order to read and understand this history, it seems necessary that we should be able to distinguish between the fragmental and non-fragmental forms; the characters assumed by a lava flow and its associated detritus, their relations to one another and to the over and underlying rocks; the characters of an intrusive rock, its effect upon the country rock, and the nature and kind of junction that they make with each other; the relations that sedimentary rocks have to their over- and under-lying rocks; and the alterations to which all classes are subjected. One of the most common errors made, is by observers taking the ground that two outcropping rocks that look alike are of necessity the same geologically, and form a continuous whole, although no direct connection is proved.

It now remains for us to enter upon the questions before us.

The Jasper and Iron Ore.

The country rock is of a varying nature, but is mainly composed of schists (largely chloritic), argillites, and quartzite, in that part of the district visited by us. Associated with these rocks is the jasper, which is acknowledged on every hand to be an inseparable part of the iron ore formation. The origin of one gives the origin of the other. Their interdependence is such, and has been so regarded, that the relations of one to the country rock give the relations of the other. The two have been so fully described in the past, that it is only necessary to briefly describe them here.

The common form is that of interlaminations of jasper and iron ore, the laminæ varying from extreme tenuity to considerable thickness. In some places the jasper predominates, in others the ore. In the last case we have a more or less valuable ore, according to the amount of the siliceous material, which, however, may exist only in a mere trace. The purer parts form large masses, that are mined, and which graduate into the jasper, or ore containing so much jasper as to be unfit for working. The workable parts are frequently lenticular in form, although often irregular. The irregularity of the ore mass, its passage into the jaspery ores, and the uncertainty where the next mass will be found, are among the chief difficulties of the miner. The origin of the jasper and ore becomes then a problem of great economic importance, as do also the relations of both to the country rocks. The permanence and extent of the formation, whether it is in the form of vein deposits, eruptive (intrusive or overflow) masses, or sedimentary deposits, are questions in which the capitalist and miner, whether they will or not, are most deeply interested. As they have never been regarded as vein deposits, there remains for us only the question whether the jasper and its associated ores are eruptive or sedimentary in origin.

Lest there be some misunderstanding as to to the reason for thus dismissing the theory of the ores here being vein deposits, we would remark that the question has been ably and fully discussed before in the works of previous observers. Furthermore, while veins on a small scale are occasionally seen, we were unable to find upon either the jasper or its associated ore a single character belonging either to a vein or an infiltration deposit. It therefore seems unnecessary to discuss the vein or infiltration theory here.

As both the eruptive and sedimentary origin of the jasper and the ore have been advocated by some of the most eminent geologists in this country, it is necessary that the question should be answered by the facts, and not by any preconceived theory or idea. The question now is what are the facts, and their most probable explanation. The first and most important thing to be observed in deciding this is the relation of the jaspery formation to its country rocks.

This relation is well shown in and about the Lake Superior mine at Ishpeming. On the north side of one of the abandoned pits just east of the main workings, the junction of the jasper and ore with the chlorite schist was observed and figured. (Fig. 1.) Specimens were also taken that show the contact (143, 144, 145, 146, and 147).* The junction of the two is very irregular, the banding of the jasper and ore following the irregularities of this line, while the schist is indurated and its laminæ bear no relation to the line of contact. Stringers of ore project into the schist, which near the jasper is filled with octahedrons of magnetite. The schist loses its green color generally, and becomes apparently an indurated argillite. The contact and relations of the two rocks are not such as are seen when one sedimentary rock is laid down upon another, but rather that observed when one rock is intrusive through another; and in this case the intrusive one is the jasper and its associated ore. On the south side of the same pit the jasper bows in and out in the schist, forming at one place a projecting knob whose banding follows its contour. Lying against it is a long arm of jasper, similarly banded, which ends in a rounded knob. This is represented in plan (Fig. 2), and specimen No. 150 was taken from the end of the latter projection. In the southwest corner of the same pit a dike of very fair hematite ore (155) about one foot in width breaks at an angle of 15° across the argillite (154) and schist, whose lamination is vertical. (Fig. 3.) Wherever the unbroken contact of the jasper and ore with the schist could be observed, that junction is seen to be an eruptive one, on the part of the former (156, 157, and 158). At the School-house mine east of the Lake Superior mine, the jasper forms a dike with a knob-like ending, the lamination (banding) following the curvature of the sides. The contacts between the ore and schist were well-marked eruptive ones (168, 169). Overlying the ore was found on one side a ferruginous and quartzose breccia and conglomerate composed principally of the ruins of the underlying ore and jasper (166, 167). A similar but finer-grained rock, mostly a quartzite, forms the hanging, or better the fallen wall of the New York mine. This is composed, in like manner, chiefly of the *débris* of the underlying ore and jasper. Mr. Brooks's statement regarding the "quartzite" of the Marquette district (p. 18) is undoubtedly true of this rock, that when he finds the "quartzite," adjacent to it will be found all that is left of the ore formation. This, however, is not what Mr. Brooks intended in his statement, as these detrital rocks apparently form but a small portion of his "quartzites." These of course mark old beaches water-worn after the jasper and ore were *in situ*, in nearly their present condition, and, if the logic of the geologists of the Michigan and Wisconsin surveys were carried out, these unconformable detrital formations would mark a new geological age.

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* The numbers enclosed in marks of parenthesis refer to specimens collected by the writer, and deposited in the Lithological Collection at the Museum of Comparative Zoölogy.

One difficulty found in mining the iron ore has arisen from the schist being found in large masses, broad at the upper part of the mine, but tapering out to thin wedge-shaped masses below, which are left without support when the ore is removed. This renders one wall, and sometimes both, unsafe, no one foreseeing when the support to the treacherous schist will be removed. This structure evidently is consonant with the theory of the eruptive origin of the jasper and ore. They break obliquely up through the schist, and send off branches, which, pursuing the same general course, leave wedge-shaped masses between them and the trunk. The ore when removed allows that which has been supported by it to fall. This very cutting across the lamination, however slightly, would tend to let all severed masses slide out, even if they were cut on one side only. Figure 4, taken from an actual section in an old working at the southeastern end of the Cleveland mine, Ishpeming, shows the phenomenon very well, and its cause. The branches of ore are about two to three inches wide here, the main body being about twelve inches in thickness, and the relations can be well studied. In several places near this point the irregular wavy line of contact between the schist and ore can be seen; and all bodies of this or the jasper were found on close examination not to coincide with the lamination, however much they may appear to do so.

At the upper portion of the Jackson mine, Negaunee, the jasper and hematite were seen to cut across and obliquely up through the schists. A vertical section as shown by the former mining done at this point is given in Figure 5. The jasper also curves in a similar manner at right angles to this nearly east and west section. While this (the figure, not the actual occurrence) could be explained easily by sedimentation, it is fatal to the view of conformable deposition. In pit No. 3 of this mine (Jackson) the ore breaks irregularly through the schist, forming a brecciated-looking mass, while in other cases it runs up into the schist ending in irregular knobs. Figures 6 and 7 show some of the occurrences observed and figured from the pit walls. Figure 8 represents a section about forty feet in height at the west end of No. 7 pit in the same mine. The schist shows bending and dislocation as represented in the curve *b*, *c*, which shows the direction and manner of the upthrust. The point *a* is at such an elevation that we are not able to assert that it is part of the same formation. It certainly looked the same, and the assistant captain in charge of the pit stated that he knew they were the same. The entire mass of jasper and ore represented here had been so acted upon by secondary agencies that it had been mined as "soft hematite." In the same pit a beautiful brecciated jasper occurs in which the hematite forms the cementing material (269, 270, 271, 272).

In pit No. 4 a wedge of ore and jasper was seen intruding between and across the lamination of the schist. (Fig. 9.) In the "north pit" the eruptive character of the ore is well shown; Figures 10, 11, and 12 showing sections exposed on the walls. Overlying the ore at a low angle is a quartzite containing jasper and ore derived from its underlying ore (277). At the Home mine in the Cascade range the ore was largely a sandstone impregnated with hematite (257), strike N. 70° W. with a northerly dip, which varies owing to the contortion of the strata from 30° to 70°. Several dikes of jasper run through this sandstone, in part conforming to the bending of the strata, and in part breaking across the laminæ (258, 259, 260, 261). Specimen 259 shows well the contact between the two rocks, the jasper and sandstone, which contact in a less degree is shown by the other specimens. One of these dikes is represented by Figure 13, in which the width is exaggerated compared with the length. There is no mistaking the intrusive character of the jasper and its interlaminated ore here. It is of course almost unnecessary to state that this mine, having as its chief ore a ferruginous sandstone, was long since abandoned. The quartzite (metamorphosed sandstone) which forms the hanging wall of the Pittsburg and Lake Superior mine, Cascade range, has been cut through by dikes and little stringers of nearly pure hematite (262, 263, 264), which in its present position is distinctly intrusive. While in general these little dikes follow approximately the bedding, they are seen not to exactly do this, but cut the laminæ obliquely through much of their course. This mine contains as a secondary formation much specular iron (265). Near the bridge over the Palmer mine the jasper shows well its eruptive character in its junction with the quartzite, while the banding is seen to be parallel to the contact line. This jasper holds in it, and as part of itself, the hematite mined here.

It is advocated by Messrs. Credner and Brooks that all the iron was originally in the state of magnetic oxide, this view being sustained by the crystals of martite found in various parts of the district.

It would seem that a microscopic examination of the banded jasper and ore should give us some facts bearing upon the question. A section was made of a finely-banded jasper (136), taken near the Lake Superior mine. Under a lens this shows a fine contorted banding. Microscopically this section is composed of a fine granular aggregate of quartz and hematite, and a more coarsely crystallized portion made up of octahedrons of magnetite or martite, and of quartz of secondary origin. The quartz in the first part is largely filled with minute globules and grains of ore, which also occurs in irregular masses and in octahedrons. The quartz associated with the more coarsely crystallized portion is water clear, and shows the usual fibrous granular polarization of secondary quartz. Wherever the iron is in a distinguishable crystalline form it is in octahedrons. The color and streak of the iron in the hand specimen are those of hematite, but the powder is found to be magnetic. No. 153, from the same locality, has similar characters. The section was taken from the most jaspery portion, and shows much of the fine aggregation of quartz and hematite. The structure of the quartzose portion is like the devitrification structure of the rhyolites and felsites. The section has been repeatedly fissured, and the fissures filled in with secondary deposits of quartz and octahedral crystals of iron. So far as we have observed, the brecciated jasper and ore have had their fractures filled in like manner. No. 271, from pit No. 7, Jackson mine, is of similar character. The jaspery portion is finely banded, and shows an apparent fluidal structure. We are inclined to regard the structure as fluidal, but in a rock so deeply colored it is difficult to make satisfactory examinations. This is the only section that shows anything like a well-defined limit between the jasper and ore bands, under the microscope, as pointed out by Dr. Wichmann.* The powder of the two last-described specimens is feebly magnetic. No. 262 was from the Pittsburg and Lake Superior mine, Cascade range. This shows the intrusion of the iron ore through the quartzite (p. 32). The ore gives the hematite streak, is feebly magnetic, and appears to be in octahedrons. The quartz is much fissured, showing the effect of heat, and contains microlites and fluid and stone inclusions.

The octahedral form of the iron ore would sustain the view that it was all originally magnetite. The difficulty lies in proving the crystals to be primary, and not secondary forms, especially as they are largely associated with secondary quartz, and also are abundant in the little fissures (minute veins) traversing the jasper. Our microscopic examination of rocks of various ages and characters goes to show that all rocks, especially the older, have been subject to more or less alteration. This alteration is accompanied by recrystallization, which often obliterates the original characters. This change appears to be produced through the medium of the percolating waters, and consists rather in a chemical rearrangement of the constituents of the rock amongst themselves, than in the deposition of any material brought in from extraneous sources. The jasper and iron ores, as well as all other rocks examined microscopically from this district, have suffered this alteration to a greater or less extent; therefore it is perhaps impossible at present to be sure of the original state of the iron, or how many changes have taken place.

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* Geol. of Wisc., III. 615.

Without objecting in any degree to the idea that the ore was originally magnetic, certain facts indicate that the present magnetic state of the iron is in some places due to secondary causes; i. e. the heat of intrusive rocks erupted since the iron ore and jasper were in place. While in general the Republic Mountain ore is hematite, exceptions exist. On the northerly side of the hill a "diorite" dike was seen (91, 92). It is found that the ore was so affected by the heat of this intrusive mass that it is magnetic adjacent to it (90), while a short distance away it is the normal hematite. Numerous other localities were examined about the hill where these secondary intrusions occurred, with the same result; the iron ore was magnetic adjacent to the dikes, but not magnetic a short distance away. As a general rule, the magnetite or the hematite pseudomorphs after it (martite) are found near the "quartzite" of Brooks in this mine. Those who examine the map of Republic Mountain, prepared by him,* will observe on the northern side of his "quartzite," a queer tongue of it projecting into the hematite. An examination of this tongue at different places shows the following facts. It contains numerous rounded and irregular fragments of the iron ore in it; these fragments occur on both edges (93, 94, 96), while the centre of the mass is free from them (95). At this point it varies from a few inches to two feet in width, and it is seen to break across the lamination, although nearly coinciding with it. At another part, shown near the same pit, No. 8, this rock and its contact with the "jasper" and ore were well marked. The "quartzite" (115, 118) is firmly welded to the ore, and breaks across the laminæ, cutting them, and sending tongues into the mixed jasper and ore (116, 117, 119). The junction is an eruptive (intrusive) one, and not that belonging to the contact of one sedimentary rock with another. The ore at the junction is magnetic. The question whether this is an intrusive or sedimentary rock has another side than the simple scientific one. It makes a great difference in the mine whether this is a simple overlying metamorphosed sandstone, as Mr. Brooks places it, or a later intrusion cutting the ore below. This latter case opens up numerous questions that the practical man can only disregard to his cost, sooner or later, but which have nothing to do with the present discussion.

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* Atlas, Geol. of Mich., 1869-73, Plate VI.

As this rock seems to belong to the granites, it will be described under them (p. 54). Should future research show that all of the "quartzite" of Republic is the same as the tongue is, it would have a bearing on the proximity of the magnetite and martite to it.

In like manner, passing to other mines where secondary intrusions are more abundant, the magnetite becomes a more prominent feature. It seems, so far as we have seen, that the magnetite and martite are directly proportioned to the amount and proximity of eruptive rocks, extravasated since the ore was *in situ*.

East of the Old Washington mine, Humboldt, the actinolite schist (310) and jasper with its ore (magnetite) were seen within one hundred feet of one another, but dipping in opposite directions; three hundred feet farther west they both dip in the same direction, while a few rods away the magnetite (311) with the jasper is seen breaking irregularly through the schist (312), and sending tongues into it.

The intrusive nature of the ore was well marked here, but it was very difficult to procure any hand specimens showing it (313, 314, 315, 316). An attempt had been made to mine the ore at this locality. Three rods to the east the ore and jasper were seen intruding in long tongues and sheets between the planes of the schist, as well as breaking across the lamination (317, 318). The same structure is very well marked in the rocks that form the bluffs between the Old Washington and Edwards mines. The ore with quartz (325) sends long tongues up between the laminæ of the actinolite schist (326). Although in part these coincide with the bedding, yet in many places they break obliquely across it, showing their intrusive character in an unmistakable manner.

It would seem that this intrusion between the planes (intrusive sheets) in this locality probably took place when the schist was in a somewhat unconsolidated condition, the intruded rock serving as an efficient agent of metamorphism. The effect produced by the ore and its relations to the schist are not such as we should expect, or are accustomed to see, when a rock is intruded through one indurated as the schist is now. The ore at the New Washington mine is magnetite, and it was seen in distinct well-marked dikes, as unmistakable as any dike, breaking obliquely up through and across the argillaceous schist, No. 340 showing the contact of the two. These dikes were sometimes narrow, being only about one foot wide, with well-marked junctions with the schist on both sides. The ore is more strongly magnetic and affected in its character adjacent to the dikes that later cut through it than in other portions of its mass (p. 43). The dikes of magnetite, with the other dikes, have greatly affected the schist through which they pass, forming an ottrelite schist (p. 45). At the Champion mine the ore is both magnetite (356) and hematite (355), and both are frequently found in a single hand specimen (357, 358, 359). At the Keystone mine, east of the Champion, a dike of magnetite about six inches in width was observed.

The Basic intrusive Rocks, Schists, and Felsite.

At Marquette, south of, but near, the lighthouse, a dike (3) of about seventeen feet in width cuts across the schist (1, 2, 5,), the latter dipping north seventy degrees. The contact of the dike with the schist is a well-marked intrusive one, the schist being indurated at the point of contact (4). (Fig. 16.) Microscopically, the rock of this dike (3) is composed of plagioclase, some orthoclase, quartz, hornblende, biotite, viridite, magnetite, hematite, and some probable pseudomorphs after olivine. The feldspar contains numerous microlites and inclusions, and it appears to be the only original constituent of the rock left in a determinable condition, except the magnetite. The schist (2) is composed of a fine-grained groundmass of aggregately polarizing quartz, holding greenish ragged hornblende crystals and grains of magnetite.

Many dikes occur in this vicinity, and their intrusive character has been noticed by Credner, Rominger, and Julien. Some dikes (8) were seen running north and south, cutting the east and west ones. The relation of one of the latter to the adjacent schists is shown in Figure 14. In the quarries near the light-house numerous dikes were seen. Their lines of junction with the schists (47) could readily be made out, and hand specimens obtained showing it (45, 46, and 48). (Fig. 15.) Four of these dikes were counted within a distance of two hundred and thirty-two feet, one of which was sixty-six feet in width (49). The locality is the place from which the stone for the Marquette breakwater was obtained. These dikes, like the majority running east and west, nearly, but not quite, coincide with the bedding (45, 46, 47, 48, 49). A specimen of one of these (45), taken near the edge of the dike, is composed of plagioclase, orthoclase, magnetite, titaniferous iron, hornblende, viridite, quartz, epidote, and augite. The augite is generally nearly altered to hornblende and viridite, only a little of the distinguishable augite remaining in the centre of the crystals. The other constituents, except part of the feldspar and the iron, bear the characters of alteration products. A section adjacent to the junction with the schist shows much higher alteration. The augite has disappeared, the iron has been nearly all altered to "leucoxene," and secondary orthoclase is abundant. The schist from the same specimen (45) is composed of quartz, argillaceous material, chlorite, hornblende, magnetite, "leucoxene," and a little augite. It would seem that this has been formed from detrital material of the same nature as the dikes (basaltic). The close resemblance of the "diorite" and schist in mineralogical characters, but not in structure, is shown in another section containing the junction of the two rocks (48). No. 49, taken from the centre of the dike, sixty-six feet wide, running parallel with and belonging to the same system as the others, is composed of plagioclase, augite, magnetite, olivine, and some viridite. Long microlites of apatite traverse the mass in various places. The feldspar contains numerous inclusions of the original base, more or less altered, of the same general structure, relations, and arrangement as is commonly seen in the feldspars of modern basalts. The portions of the base originally left in the crystallization of the molten magma in the interstices between the crystals has been changed to a grayish or brownish fibrous substance, also to viridite. The augite is comparatively fresh, and cut by the feldspar crystals. The structure of the rock is that belonging to the more coarsely crystalline basalts. The altered base is probably the "inserted substance" of Drs. Zirkel and Wichmann.* It would seem that some of the above rocks are like the "diorite" of Dr. Wichmann from this locality (*l. c.*, p. 629). We feel that the lithologist who was unacquainted with the field relations of the preceding specimens would declare it impossible that they could be from the same series, apparently identical in age, and originally so in composition. South of Marquette the schists (11) are more argillaceous, forming true argillites, although chloritic in places. Numerous dikes were seen here, but the rock is more altered, and perhaps was extravasated earlier than most of the dikes on Light-house point (9, 10, 12). No. 12 is composed of feldspar, quartz, viridite, opacite, and pseudomorphous remains of hornblende fragments. But little of the feldspar shows the twinning of plagioclase. The structure of the rock renders it probable that it was originally an andesite. On Light-house point, lying just north of the dike (No. 3, page 36) first described, and older than it, is an intrusive felsite (quartz porphyry). It is to be here noted that Mr. T. B. Brooks states: "It may be confidently asserted that no porphyry occurs in the Marquette . . . . Huronian";* also that this locality has been studied by Messrs. Julien, Credner, Rominger, and others, without finding this felsite.

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* Geol. of Wisc., III. 624.

This felsite is eruptive generally along the lamination planes of the schist, but at certain points breaks through and across those planes. Figure 16 gives a good idea of its relations to the schist and diabase, for such we regard the rock of the dike to be. A short distance to the north, on the opposite side of this immediate spit of land, its eruptive character is better marked than in the first locality.

The felsite (6) on its weathered surface is colored pinkish and greenish white, showing fluidal structure, and holding crystals of quartz and pinkish feldspar. On the fresh fracture the groundmass is felsitic, of a greenish-gray color, and holds the same crystals. Pyrite is seen in the fissures. The groundmass is now altered to an aggregate polarizing mass, principally of quartz and mica. The fluidal structure is seen in the thin section, and greenish and brownish mica is largely segregated along the fluidal lines. The feldspar is entirely decomposed, having about the same composition and structure as the groundmass, but holding more argillaceous material and less quartz. Chlorite and magnetite were observed. The original quartz grains are filled with fluid and vapor cavities, and also contain some stone cavities and microlites. Northwest of the light-house a more quartzose felsite (7) was found on the side of a bluff overhanging a little ravine. This felsite is very much jointed, breaking into small rhomboidal blocks, and cuts through the schists nearly, but not quite, coincident with their lamination. It is a grayish-white rock containing crystals of feldspar, quartz, and pyrite. Microscopically, the groundmass is now altered to a fine granular aggregate, as in the preceding, holding quartz, muscovite, greenish mica, and pyrite. The feldspar is altered the same as the groundmass, and contains similar minerals. The original quartz grains contain microlites, stone inclusions, fluid cavities, etc. We regard these felsites, from their structure, not as the equivalents or precursors of the Tertiary rhyolites, but as identical with them, the present difference between them being due to secondary alteration, and perhaps their somewhat greater depth at the time of consolidation than the part of modern dikes reached by us had.

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* Geol. of Wisc., III. 660.

On Picnic Point, north of Marquette, a coarsely crystalline diorite (50, 51, and 52) occurs, forming the main portion of the point. This rock contains pebbles and fragments (53, 54) in some places. Some of the fragments of schist are large, and one long band of it was seen. This schist is much indurated, especially near its contact with the diorite (58, 59), and forms an irregular junction with it (57). Picnic Islands, just off the point, are composed, in the main, of the same rock (60).

On the North Island, a diabase dike (61), about twenty-eight feet wide, cuts the "diorite," running S. 80° E. Another dike was seen running the same way, on the Middle Island. The "diorite" is somewhat brecciated. On Picnic Point a hornblendic granite (55) cuts up through the diabase, and includes numerous fragments of it (56). The general structure and relations of the granite to the "diorite," as well as the rounding off of the "diorite" fragments, are shown in Figure 17. The order is, then, 1st, the schists; 2d, the "diorite"; 3d, the granite and diabase, — the question of the priority of either not having been settled.

The "diorite" (50) is a grayish-black rock composed of hornblende crystals, with reddish feldspar, epidote, and pyrite. Microscopically, it contains the same minerals with magnetite and apatite, as well as chlorite, quartz, viridite, and other alteration products. The feldspars are greatly altered, give aggregate polarization, and are filled with alteration products.

The most coarsely crystalline specimen (52) is a grayish-green rock, composed mostly of short, thick hornblende crystals, showing well-marked cleavage. With the hornblende a small amount of feldspar occurs. Under the microscope, besides these, augite, chlorite, quartz, titanite, hematite, actinolite, and magnetite were seen. The hornblende and chlorite appear to be products of alteration from the augite, and the hematite from the magnetite. Some of the feldspar can be recognized as plagioclase, and it would seem that the rock was originally composed of feldspar, augite, and magnetite, while the other constituents are alteration products. The quartz contains fluid and vapor cavities.

The diabase dike rock (61) is a dark gray crystalline one, holding ledge-formed feldspars and weathering brown. In the thin section it is seen to be composed of plagioclase, a little orthoclase, augite, olivine, magnetite, hematite, viridite, and apatite. The feldspar encloses bits of the original base, part of which is now devitrified, but part remains as an unchanged globulitic base. This affords additional proof that the diabases are simply old crystalline basalts. The augite is quite clear and unaltered except in some places. The olivine is considerably changed, yet the centre frequently shows the unchanged mineral. These olivines, like those in modern basalts, are in fragments, grains, and rounded and penetrated crystals, showing in this way their prior origin to the crystallization of the rock *in situ.*

In the sketch of the literature given before, it is seen that Messrs. Rivot, Kimball, Hunt, Winchell, Credner, Brooks, and Wright regard the so-called "diorites" as sedimentary rocks, metamorphosed *in situ,* and in general teach that they gradually pass into the schists on either side; i. e. they form one and the same inseparable series of sedimentary deposits. This passage, by insensible gradations, it is said, was established by the field observations of all except Dr. T. Sterry Hunt, who, it seems, based his conclusions upon lithological evidence; for we fail to find the slightest evidence in his writings that he had any personal acquaintance with the district. On the other hand, Messrs. Foster and Whitney taught that these rocks were intrusive, basing their conclusions upon their observations in the field.

Special pains were taken by us in the field to see which of the two views were correct. Where the conditions were such in the field that any evidence could be obtained bearing on either side, that evidence was always of the positive kind, and sustained Messrs. Foster and Whitney. The evidence of the six observers quoted on the opposite side was of the negative kind; i. e. they could not or did not see any distinct junction between the two rocks; therefore it was assumed that none existed. Where the contacts were covered, or broken and obliterated by frost and atmospheric agencies, the proof on either side is *nil;* but when such is not the case, and we have on one side "diorite" and on the other schist, the question is, Do they or do they not pass into each other? Both rocks are of a greenish hue generally, and to the eye untrained to observe the minutest changes and differences in rocks, they look alike. It is therefore to be expected that the majority, at least, of observers will walk directly over the junction between two rocks, especially if they believe in the prevailing theories, and declare that they pass directly into each other by insensible gradations. The only thing such negative evidence gives in this case is the proof that either the observer was unskilled, or else his work was not done with sufficient care, perhaps both. The line of contact is, when found, a distinct separation between the two rocks; on one side of which is to be seen schist, on the other "diorite." They no more pass into each other than do oil and water in the same vessel, although it might not be impossible that some would not be able to say where one ended and the other began. The contact of the two rocks is so well marked that hand specimens (171, 172) can be obtained showing it; therefore our proof that they do not pass into each other, but are entirely distinct formations, can be examined not only in the field, but also in the cabinet, and if need be under the microscope.

Such a contact between the schist and "diorite" can be seen a short distance east of Ishpeming, where the carriage-road, near the railroad leading to Negaunee, bends around a low "diorite" knob. This junction is represented in plan (Fig. 18) by a sketch made on the spot, and shown by specimens 171, 172. The "diorite" at this point appears to have passed obliquely up through and over the schist. The relation that the two have, the kind and manner of contact, are those belonging to an eruptive rock breaking through and partially over another. It is almost needless to say that the "diorite" is the eruptive rock here. Many of the "diorite" hills, if not all, are composed of dikes of the "diorite," with schist and argillite lying between. The lamination of these interlying masses is of course generally perpendicular to the pressure, i. e. parallel with the dikes. This can be well seen in the hills south of Teal Lake, Negaunee, as well as just northeast of the Cleveland mine, Ishpeming. At the latter place the "diorite" is seen to break obliquely through the schist, and the line of junction can be easily seen. (Fig. 19.) So far as can be told, the "diorite" comes out obliquely over the schists connected with a narrower neck below, as shown in ideal section. (Fig. 20.) This would indicate, we think, that this is somewhat near the old surface of eruption. This hill was seen to be made up of several "diorite" dikes, with schist held between them. The contact of two of them with the schist is shown in Figures 21, 22.

At Negaunee, on a little elevation between Main Street and the Marquette, Houghton, and Ontonagon Railroad, the "diorite" is seen to break through the schist, and to send small veins into it. On the "diorite" ridge south of Teal Lake, the "diorite" is seen (243+, 282, 283) to have cut through and enclosed between it some schists and argillites. This rock is very columnar, and has the general character of an eruptive mass. Its junction with the schists is well marked, and was observed in various places. One specimen is seen to be composed of augite, hornblende, feldspar, viridite, titaniferous iron, and epidote (243+). The augite is much altered, changed to viridite and hornblende. Another section (283) shows no augite, this mineral being entirely replaced by the secondary hornblende. The feldspar is so greatly changed that only part of it shows its triclinic character. Of a similar character to No. 283 are Nos. 238+ and 239+, from the "diorite" south of Lake Superior mine, neither showing any augite, although the hornblende is doubtless secondary, as in the others. No. 239+ is more coarsely crystalline and granitoid in its structure.

The "diorite" (180) lying between the Lake Angeline and Salisbury mines is seen in the thin section to be composed of plagioclase, hornblende, biotite, epidote, viridite, and titaniferous iron with its alteration product. Of these only the feldspar and titaniferous iron are apparently original constituents.

The diabase (175) forming the southeast side of the Salisbury mine is a dark gray crystalline rock, holding ledge and tabular formed crystals of feldspar, and weathering to a rusty brown. It makes a most beautiful section under the microscope when studied in polarized light. It is composed of plagioclase, orthoclase, augite, magnetite, olivine, viridite, and hematite. The plagioclase cuts through the augite, leaving it in cuneiform and irregular masses. The olivine is in rounded and irregular grains of prior origin to the crystallization of the rock, and is held both in the feldspar and in the augite. It holds a similar relation here to the feldspar that it does to the enstatite in the Presque Isle peridotite. While the central portions of the olivine are sometimes clear and unchanged, the grains are generally altered to a greenish or brownish serpentine. A little fissure traverses the section, cutting and connecting a number of the olivines. This fissure can be readily traced under the microscope on account of its having been filled throughout its extent with the greenish serpentinous material derived from the olivine. The feldspar is in some cases nearly filled with stone inclusions, arranged parallel to the crystalline faces. These inclusions are evidently inclusions of a devitrified base. This dike is said to ascend by steps, not in a straight line.

Near Deer Lake, northwest of Ishpeming, a "diorite" dike running N. 45° W. (231) was seen cutting a breccia and conglomerate (229, 230). This "diorite" is so altered that it resembles a chlorite schist, and in the thin section is seen to be composed of chlorite, quartz, and mica. It holds some ferruginous masses resembling the product of the decomposition of titaniferous iron, as well as one or two that probably resulted from the decomposition of olivine or brown hornblende. The quartz contains fluid inclusions. The groundmass is now composed entirely of scales, plates, grains, and microlites belonging apparently to chlorite, mica, and quartz, and with the exception of the ferruginous decomposition product no trace of the original structure and constituents remain. We regard the rock simply as a more highly metamorphosed condition of the "diorites" of the region; but were it not for its field relations we should not be able to tell its history from microscopic examination. In such a case as this, with our present knowledge, the microscope fails to give us any idea of its origin, whether eruptive or sedimentary. Probably every lithologist, in examining this section, would pronounce the rock to be sedimentary, yet we know it to be eruptive, and probably in its original state a basalt. This well illustrates the danger of deciding upon the origin of such highly altered rocks by microscopic analysis alone, and calls attention to the necessity of carefully ascertaining their relations in the field.

One mile northwest of Deer Lake, west of the road, a high hill was seen composed principally of "diorite" (232) running about north and south. The contact of this "diorite" with the country rock is well marked on both sides. On the west side it cuts a conglomerate, and on the east a finer-grained fragmental rock (233). The contact is an irregular eruptive one, and the country rock is indurated near it. At the south pit of the Jackson mine, from which "soft hematite" is taken, a diabase dike forty feet wide was observed running N. 30° W., and cutting the ore. It was said that in mining its course had been found to be variable. This diabase is a grayish brown, coarsely crystalline rock composed of plagioclase, orthoclase, augite, brownish decomposed olivine, magnetite, and ferrite (278). The plagioclase is but very little decomposed, and is beautifully striated. The diabase (280) near its walls was very much decomposed, and its olivine, augite, and magnetite form a dark brown decomposed mass cut through by the feldspar crystals, which are kaolinized, forming feebly polarizing masses. Were it not known that it is part of the diabase, it could only be recognized as such from the position and arrangement of its kaolin pseudomorphs relative to the remaining portion of the section.

In the Washington mine several dikes of "diorite" and melaphyr cut the ore, which is strongly magnetic in contact (327, 328) with them. The melaphyr (329, 342) encloses a horse of jasper and cuts the "diorite." It (329) is composed of plagioclase, a little orthoclase, augite, magnetite, and viridite. The structure is that belonging to basalts, and the rock is comparatively little altered considering its age. The feldspars contain inclusions that appear to have been portions of the original base, but which, as well as the base adjacent, has been altered to a grayish-white globulitic and fibrous material. This shows largely the structure of the original globulitic base, but wants the black color. The fibrous alteration product of the base has been confounded with the true original micro-felsitic base of the andesites by lithologists generally; as is the inevitable result of studying the constituents of rocks without regard to the origin of these constituents. A very little of the original globulitic base was found unchanged in some of the feldspars. Numerous microlites extend through the groundmass that belong apparently to apatite. This is probably from the same dike that No. 1110 of Mr. Brooks's collection, described by Dr. Wichmann, was obtained.* The "long, small rod-like crystals" in which the plagioclase is said to occur is the usual ledge form which belongs to basaltic plagioclase. The "inserted substance, which has not been individualized," is doubtless the altered globulitic base. No biotite or hematite were seen in No. 329, which was selected with direct reference to procuring as unaltered a specimen as possible, as well as one removed from the influence of the ore and jasper (342) through which the melaphyr cuts. A section showing the junction of the two rocks (342) was made. The melaphyr here becomes a dense black opaque mass, containing a few ledge-formed plagioclase crystals and some decomposed (viriditic) augite. This part is probably an altered tachylitic glass, such as occurrs in similar positions in basalts. The junction with the jasper is well marked, and more regular than one would expect to find it. The globulitic structure shows well in the melaphyr at this immediate line of contact. The "jasper" is composed here of quartz and magnetite. The quartz is in part fine granular, and filled with magnetic dust; while the remainder is coarsely granular, having the same structure as the granite (greisen) southwest of Republic Mountain (No. 128, p. 53). These quartz grains were formed by the fissuring of a quartz mass, not built up of detrital quartz grains, as is the case with a true quartzite according to the definition employed by us. The quartz contained numerous fluid and stone inclusions, as well as microlites, magnetite, and lenticular scales of probable muscovite.

The "diorite" (334, 335) cutting the magnetite yielded specimens showing a well-defined contact (337, 338, 339). No. 335 is a greenish-gray rock composed of hornblende, holding patches of quartz, which contains crystals of tourmaline. The rock holds an abundance of magnetite, in part at least torn from the ore through which it passed. The quartz contains fluid and other inclusions. The schist at this locality is an argillaceous one (340) resembling that found at Republic Mountain, Ishpeming, and Negaunee; but it has been so affected in places by the combined action of the magnetite and other dikes that it has become an ottrelite schist (336). This rock has a dark gray groundmass, holding crystals of ottrelite and minute ones of tourmaline. In the thin section the groundmass is of a clear grayish-white color, and holds ottrelite, tourmaline, and magnetite. This groundmass is composed of a clear talc-like mineral in flakes and scales, apparently orthorhombic. In it occur magnetite grains and irregular masses of this mineral, as well as greenish micaceous scales. The ottrelite in the section is of a green color, shows dichroism, varying from a light to dark green, and contains scales of the talc-like mineral, magnetite, etc. In polarized light it shows a banding generally of lighter and darker shades of the same color. Its edges are broken, step-like, and irregular; and it shows cleavage parallel to the basal and lateral planes. In microscopic characters it and the masonite of Warwick, R. I., are closely alike. The tourmaline is in elongated crystals containing grains of magnetite. All the minerals in this rock are of later origin than the magnetite.

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* Geol. of Wisc., III. 625.

South of the Champion mine dikes of diabase (346) and "diorite" (345) occur in the granite and gneiss. A "diorite" that was undistinguishable from that in the gneiss (345) was found at the east end of the Champion mine, in the "Huronian." This "diorite" contains patches of quartz, which hold crystals of tourmaline in radiated groups. The "diorite" (345), running north and south in the "Laurentian," cuts both the granite and the gneiss, and is composed of hornblende, biotite, quartz, and magnetite. Traces of some of the larger and more porphyritic feldspar crystals remain in a kaolinized mass, containing flakes of biotite and grains of quartz. Were the origin of this rock unknown, it would pass for a sedimentary hornblende schist, so far as the section informs us of its nature. The diabase (346) is comparatively fresh, and is undistinguishable from the diabases seen in the "Huronian." It is composed of augite, plagioclase, a little orthoclase and quartz, magnetite, viridite, and some decomposed olivine.

Another dike (343), cutting the gneiss at this locality, is seen to be composed of hornblende, quartz, feldspar, and magnetite.

On the northerly side of Republic Mountain a garnetiferous "diorite"

(91, 92) was observed cutting across the iron-bearing rocks, bending and breaking them at the junction between the two. The "diorite" holds fragments of the iron-bearing rocks in it, and cuts very irregularly through the schists. Its intrusive character is distinctly marked by the relation which it holds to the country rock. It renders the rock adjacent to it magnetic for a little distance from the junction. A section taken from a specimen (92) free from garnets is seen now to be composed almost, if not entirely, of secondary minerals, — a confused aggregation of greenish hornblende, orthoclase, quartz, and biotite, with traces of magnetic iron. The character of the hornblende is the same as that seen to occur in those rocks whose hornblende is derived from the augite by alteration.

To the southeast of this locality, not far from the granite, the iron-bearing rocks were again found in contact with a similar garnetiferous "dioritic" dike; the former being much contorted and broken, the iron being also magnetic near the contact. A tongue of the "diorite" penetrated the ferruginous rock, and the relations were such that it was evident that the contortion was owing to the intrusion of the "diorite." The "diorite" (121) marked on Mr. Brooks's map of Republic Mountain, lying between the quartzite and Smith's Bay, is seen under the microscope to be very much altered, and composed of hornblende, biotite, plagioclase, orthoclase, quartz, and magnetite, with a little hematite. Of these minerals, it would seem from their structure and relations, that only the magnetite and part of the feldspar were original constituents.

The basic intrusive rocks mentioned in the preceding pages have, in general, been regarded as diorite, Mr. A. A. Julien especially doubting the presence of any diabase in the region.* They would pass, according to the ordinary definitions, macroscopically and microscopically, for diorite, quartz diorite, diabase, chlorite schist, hornblende schist, etc., yet we regard them all simply as more or less altered forms, according to age and conditions, of rocks that were originally the same in origin, structure, composition, and name, — basalt. Of course, the supposed altered andesite (p. 38) would be an exception. The reasons for so regarding them have been briefly pointed out in this and preceding papers.† Excepting the melaphyr of the New Washington mine, we regard them all, then, as the alteration form of basalt known as diabase.

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* Geol. of Mich., II. 42, 193.

† Proc. Boston Soc. Nat. Hist., XIX. 217-237, 309-316; Bull. Mus. Comp. Zoölogy, Cambridge, V. 275-287.

At Republic Mountain, on the southwest side, a garnetiferous "diorite" was seen in direct contact with the jasper, which was much twisted and contorted. The ore associated with the jasper was magnetic. The "diorite" was found to be intrusive here and elsewhere about Republic Mountain, breaking through and uplifting the overlying rock, whose laminæ it is seen to cut obliquely. It also sends stringers and dikes into the schist and jasper. As the "diorite" passed approximately along the lamination of the schists, and is foliated parallel to its walls, it is easy to see how those who believed that, if a rock was "striped," it was *prima facie* evidence that it was a sedimentary one, should overlook the eruptive characters. Most of the "diorites" here contain garnets, this mineral being found principally along the edges of the intrusion, while the centre was nearly, if not entirely, free from it. The schist, in like manner, near the "diorite," also frequently contains garnets, both rocks appearing to have mutually reacted upon each other. Under the microscope, one of these "diorites" (124) is seen to be composed of actinolite, garnet, quartz, and biotite. The arrangement, form, and relations of these indicate that none of them are original constituents of the rock, but all are the products of alteration.

A dike of dark micaceous "diorite" (123), some ten inches in width, was seen near this place, which contained garnet crystals varying from one half an inch to two inches in diameter, averaging about three fourths of an inch. These garnets, like the others observed, are dodecahedrons. Microscopically it is seen to be composed of biotite, quartz, feldspar, and magnetite (?) with the enclosed garnet crystals. The black grains have the microscopic characters of magnetite, although the powder is not magnetic. The biotite is the predominating mineral, and all the present constituents, except, perhaps, the supposed magnetite, appear to be secondary products. The garnet is filled with the magnetite (?). These black inclusions, so far as we are aware, have been taken for magnetite,* except some observed by Professor Pumpelly.† In polarized light the garnet is seen to contain abundantly the same grains ot quartz and feldspar that the groundmass does ; it also holds some biotite.

The "magnetic siliceous schist" of Mr. Brooks (126) near the granite (128, 129, 130) southwest of Republic Mountain (p. 53), is seen microscopically to be composed of actinolite, hornblende, magnetite, and garnet. The two first form the major portion of the section. The garnet is filled with needles of actinolite. Southeast of Republic Mountain, the same rock (No. 100, p. 53) contains longer and better formed crystals of actinolite. Besides actinolite, the chief constituent, it also contains magnetite, garnet, and a little hematite. The garnet contains inclusions of actinolite. The garnetiferous rock (97) adjacent to the granite (p. 52) is composed of actinolite, quartz, garnet, and a little secondary hematite.

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* Geology of Wisc., III. 608.

† Am. Jour. Sci., (3,) X. 20.

Southeast of the Old Washington mine a dike was seen breaking irregularly through the schists. Near the centre of the dike, the rock (305) resembles a chlorite schist, but is composed of actinolite, magnetite, quartz, biotite, and muscovite, none of which appear to be original constituents, except perhaps the magnetite. A specimen near the exterior (306) was more massive, but contained the same minerals. Part of the iron showed the decomposition of titaniferous iron. No. 307, from the edge of the dike, closely resembles a chlorite schist, and contains garnets and well-formed crystals of tourmaline. No. 308 comes from the edge of the dike, and is so filled with garnets as to resemble eklogite. Neither of the four specimens would macroscopically be taken as belonging to the same rock if their relation was not known. This is probably the rock described by Dr. Wichmann as eklogite.* The schist at the point of contact is much indurated and quartzose, and the garnets make an irregular columnar mass adjacent to it (309). They are so crowded and drawn out at right angles to the schist that their structure very closely simulates the prismatic structure of a basaltic dike. Such structure and arrangement of minerals, in a ring, parallel to the surface of the enclosed fragment, is frequently seen about quartz grains and other foreign materials included in the volcanic rocks of the Cordilleras. Several other dikes of the same rock were seen near this. All were very much contorted, breaking very irregularly through the schist, and showing intrusive characters.

The actinolite schist south of Humboldt was seen to pass into a quartzose rock made up principally of alternate layers of quartz and actinolite (319, 320). This shows very conclusively the sedimentary origin of the schist here. The banded magnetic schist of Mr. Brooks southeast ot the Champion mine (No. 348, p. 57) is seen microscopically to be composed of a thick mat of actinolite holding garnet, quartz, and magnetite. The magnetite is surrounded in many cases by thin films of hematite, derived from the magnetite, and extending between the actinolite crystals. The same hematite films extend around the garnet and penetrate along its fissures, giving it a deep red color, but leaving the centre often clear. Only a little quartz was observed.

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* No. 1091, Geol. of Wisc., III. 649.

These garnet-bearing, actinolite, intrusive rocks we cannot at present definitely place in that position which seems to us proper. In order to do that, it is necessary to have part at least of the original structure or constituents preserved; this we did not find. So far as we can judge, they are probably altered basalts or andesites, most probably the former; this conclusion is, however, liable to be overthrown by new evidence at any time. The reason for this decision is in the main their relation in minerals, position, and structure to the other highly altered "diorites," especially at Republic Mountain. The actinolite schists were in all probability formed from detritus of the same composition as the dikes, and therefore under like conditions are mineralogically about the same.

In the Lake Superior mine, a banded greenish quartz rock resembling prase was observed. In the thin section it is seen to be composed of quartz containing magnetite and innumerable little scales of greenish mica. The green color is due to the latter. Some fluidal inclusions were observed. The quartz shows the granular aggregate polarization observed in connection with the devitrification or alteration quartz in rhyolites and felsites. The relation of this rock to the ore and jasper was that of an intruding, fracturing, uplifting mass, breaking across the lamination but not reaching the surface. Above and adjacent to it in the disturbed jasper and ore "soft hematite" was found. This rock, we think, would make a very pretty object when polished.

The "Soft Hematites."

One of the best localities that we have seen to study the formation of the "soft hematite" is at the Salisbury mine, Ishpeming, just south of the Lake Angeline mine. A "diorite" hill lies between the two mines, which, when erupted, we believe upheaved the jasper and hematite lying on both sides of it. At the west end, on the north side of the hill, the Lake Angeline mine is situated, and it is still an open question whether the ore formation does or does not extend eastward along the flanks of the hill. On the southern side, towards the northern end of the hill, the Salisbury mine is located. This is a "soft hematite," which is held by Mr. Brooks to belong to a different formation, in general, from the hematite. We regard it as the same formation as the jasper and its associated ore, but which has been acted upon by thermal waters. All the writers on the "soft hematites" of this district have regarded them as formed from the decomposition of ferruginous schists by thermal waters, and on this point we are in accord. In general they regard them as peculiar to certain formations making a bed or set of beds in the stratigraphical series below the ore formation proper, while we regard them simply as local modifications of the ore formation of the region occurring under certain conditions; i. e. the conditions that led to the shattering of the rock and gave the opportunity for the formation of thermal springs. On one side of the Salisbury mine is the "diorite," while on the other comes a strong dike of diabase (p. 42). The "diorite" runs about east and west, while the strike of the diabase is about N. 50° E. The latter is seen to be the younger rock, and the marks of its passage through the "diorite" hill can be seen a long distance off. The relation of the two rocks is shown in the plan (Fig. 23), while the supposed relation of the "diorite" to the schist and ore is given in Figure 24.

The Salisbury mine is located in the acute angle *a*, formed by the two intrusives, at the point where the fracturing, breaking, and shattering of the prior or ore formation was greatest, and where hot springs would then most likely occur. The general structure of this region, the character of the ore and its associated kaolin, all confirm, in our mind, this view. As the ore deposit formed under such conditions is necessarily limited, it has become a matter of great importance to the company working this mine to find a continuation of this ore, or a new locality, before the old is completely worked out. The mining captain informed me that the State Geologist, Dr. Rominger, in conformity with his views and those of Messrs. Brooks, Kimball, and others, that the diorite, diabase, jasper, hematite, and limonite are distinct sedimentary formations, advocated the sinking of pits at the points *b*, *c*, *d*, where the formation would, by its foldings, again be brought up, and give the same ore. The point *b* is located at the obtuse angle of the junction of the diabase and diorite, therefore we should not expect so much shattering of the rock, nor so great likelihood of thermal springs. "Soft hematite" would be expected to occur to some extent, but with too much of the undecomposed jaspery rock to make it profitable mining. Such was found to be the case; therefore the theory of Messrs. Rominger, Brooks, and others failed here. If the Lake Angeline ore formation extends east along the northerly side of the "diorite" hill, the most likely place to find a deposit of "soft hematite," if our views are correct, would be at the point *h*, in the acute angle formed by the diabase with the "diorite," as it breaks through the latter. Unfortunately this point is not on the property of the Salisbury mine, and it slumbers in its primeval mud.

The McComber mine, Negaunee, is a mine of "soft hematite"; this, in connection with others lying along the same line, is near the "diorite." Part of these mines, however, lie between two hills of the "diorite." Two deposits occur on the McComber property, separated by a dike of the "diorite." The ore here, like that in the Salisbury mine, seems to occur only where the rocks have been shattered and acted upon by water. The jasper has decomposed (244+), yielding a hydrous silicate of alumina (Kaolin, Brush) (245+, 246+), quartz, hydrous and anhydrous oxide of iron, etc. The minerals associated with the ore are evidently water deposits, — barite (253), rhodochrosite (249+, 250+, 251+, 252+), manganite (247+, 248+), etc. Figure 25 shows the formation of the ore under a jasper cap, the water working in by the means of fissures on both sides.

The Pendill mine, worked for a similar ore, contains much botryoidal limonite (254). In one part the ore was worked out upon the top and sides of an oven-shaped mass, the ore following the curvature of the oven. This is similar to a form observed in the Lake Superior mine, associated likewise with limonite. In the Jackson mine "soft hematite" occurs in places, and it is seen to be associated with and to pass directly into the jasper and "hard ore," showing that they were originally the same. Water-deposited quartz (vein-stone) was found in places in this "soft ore," and a specimen was taken for microscopic examination (276), for the purpose of seeing whether it contained fluid cavities or not. It is found to be full of inclusions, most of which contain bubbles. These bubbles were, in the majority of cases, seen to exhibit motion of greater or less rapidity. Some were seen containing double inclusions, and vapor cavities were observed. All would indicate that the water by which the quartz was deposited was at a higher temperature than the rock has at present. This then would seem to confirm the views of all the writers quoted, as well as of ourselves, that these ores are derived from the decomposition of the ferruginous, siliceous rocks. That this is the correct view of their origin it would seem Dr. Hunt denies.*

The various soft ores are partly true hematites and partly limonites, mixed with more or less impurities, but of course, in general, have none of the characters of an ordinary bog-iron ore.

Our theory, of course, depends upon the relation of the "diorites" to the jasper and ore, which near Ishpeming and Negaunee is somewhat uncertain; yet there is but little doubt that the "diorite" is the later. The dip of the jasper increases as it approaches the "diorite," sometimes standing nearly vertical. It was not observed in contact with the "diorite," but we feel that the constant uptilting of the jasper and associated schists when near these intrusive rocks is good evidence that the "diorite" eruption was later than that of the jasper. The uptilting of the jasper was well seen on a hill north of the Jackson mine, where it was found, standing nearly vertical, within one hundred feet of the "diorite."

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* Geol. of Wisc., III. 660.

Granite, Gneiss, and Quartzite.

The relation of the granite and its associated foliated rocks to the schists of the Iron district is a problem of great geological importance. The diverse views have been given on preceding pages, and it is not necessary to repeat them here. The first-mentioned rocks have been accepted by the Canadian geologists (in part at least), as well as by most American ones, as the direct equivalents of the Laurentian formation of Canada, while the latter is in the same way accepted as the equivalent of the Huronian. Without going into the question of the expediency or right of establishing geological ages upon any other basis than that of organic remains, it is a fair question of inquiry whether the "Laurentian" of Lake Superior is older or younger than the "Huronian." Whose observations were the nearest correct, — those who claim that the granite is intrusive in the schists, or those who hold that it unconformably underlies them? On one side we have the statement of direct intrusive contact; on the other, the evidence afforded by the fact that the strike and dip of the foliation of the two rocks are unlike, the two formations never having been seen in contact.

It is now time to give the facts observed by us.

North of Republic, by the side of the railroad, a few rods from the depot, the granite (82) (Laurentian of Brooks) shows its intrusive character by its containing fragments of schist (83) in it, and by its cutting the main body of schist. These schists are micaceous, hornblendic, and chloritic, with a nearly north and south strike, the foliation of the granite coinciding with it. Northwest of the track, near the above-mentioned locality, the inclusions in the granite are well marked, the foliation of the granite striking S. 20° E. Southeast of Republic Mountain, separated from the supposed "Huronian" by a narrow ravine, the granite was observed in contact with a garnetiferous actinolite rock, beautifully banded and contorted (No. 97, p. 48). While this appears to us to be identical with the "Huronian" rocks, a few rods away, resembling the actinolite schists of Wichmann (100, p. 47), Mr. Brooks believes* it to be "Laurentian," for no reason that we can see except that it is associated with the granite. This rock has been tilted and contorted by the granite which is found in contact with it. The line of junction and the manner of contact show that the granite was the later rock and an eruptive one. The foliation of the granite is parallel to the plane of contact, or at right angles to the pressure. It contains fragments of schist (98), while some highly quartzose schists or quartzites (99) were seen within a few feet of it. These rocks were apparently older than the granites, and had been affected by them. On the southwest side of Republic Mountain the granite was seen about one rod from the "Huronian" schists. This is probably the locality figured by Mr. Brooks,† but the foliation of both appeared to us to be conformable in this way: the schists appeared to have been partially uptilted by the granite, which seemed to have been extravasated obliquely out from under them, very much as the peridotite was under the sandstone at Presque Isle. The foliation is parallel to the plane of pressure, and at right angles to that pressure.

The granite near the edge is fine-grained, resembling a quartzite (128), but a little distance away it is coarser and more granitoid (129). Borne upon the face of the granite next to the schists is a plate of rock about two inches thick (130). This is welded closely to the granite, and has been uplifted and altered by it. Its constituents have been drawn out in the direction of the supposed motion of the granite, and resemble in the field the altered garnetiferous "diorite" (123) described on page 47. The rock is micaceous, of a dark gray color, and contains elongated brownish-gray masses resembling altered garnets. Microscopically it is seen to be composed of biotite, muscovite, quartz, and the garnet(?) masses. The last are now composed of a finely fibrous aggregately polarizing material holding quartz grains, magnetite, and apparently hexagonal or orthorhombic opaque disks. Their nature is unknown, but they most probably belong to the margarophyllites.‡ Whether this rock was originally the same as No. 123 cannot be told, although in many respects it closely resembles it. Should it be, the granite there is younger than the "Huronian diorite."

The granite (129) is seen in the thin section to be composed of quartz with some green mica. Not the slightest trace of feldspar was found. The quartz is broken up into grains, which exactly fit to one another without any cementing material. The granular structure arises not from original water-worn grains, but from the fissuring of an originally continuous siliceous mass. The quartz contains fluid cavities, microlites, and little flakes of mica. No. 128, nearer the Huronian, at the edge of the granite, is microscopically seen to be in finer quartz grains. This rock also contains greenish mica, clusters of actinolite crystals, and garnet grains. The quartz grains contained the same inclusions as those in No. 129. Some magnetite was observed. The actinolite crystals were often seen to extend through two or more of the adjacent quartz grains, not having been broken by the process of fissuring the quartz.

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* Geol. of Wisc., III. 661.

† Geol. of Mich., I. 126.

‡ Am. Jour. Sci., (3,) X. 20.

Specimen 130 consists of two parts, — the schist already described, and the granite to which it is welded. This granite is here composed of quartz, biotite, and grains of garnet. The quartz is in the same fissured grains as that in Nos. 128 and 129, and contains microlites, minute crystals of greenish mica, and fluid cavities. The majority of the fluid inclusions lie in the secondary fissures, but part are in the solid quartz. The biotite is seen to frequently extend from one quartz grain into another without having been broken by the fissuring of the quartz. The garnet contains actinolite crystals, and the same black grains that it did in the adjacent schist (130). The biotite and garnet are evidently derived from this schist, and are in fragments. This section, more than either No. 128 or 129, shows the effect of the schist in adding foreign ingredients to the granite, and also the action of the granite on the schist by tearing off and dissolving portions of its material. Such phenomena are the usual accompaniments of the mutual reaction of two rocks when one is intruded through the other. The three sections 128, 129, and 130 well illustrate the differences that can be observed in the same rock within a distance of a few feet.

It seems appropriate to describe with the granites last given the "quartzite" (page 34) of Mr. Brooks at Republic Mountain. The rock (95, 115, 116, 117, 118, 119) is greenish gray, macroscopically containing quartz, actinolite, and epidote. Under the microscope it (115, 118) is seen to contain quartz, actinolite, hornblende, greenish mica, epidote, magnetite, and hematite. The quartz is in similar grains to that in Nos. 128 and 129, and contains numerous microlites and mica inclusions, as well as fluid cavities. This rock, it would seem, belongs to the granites adjacent to Republic Mountain, and is an offshoot from them. In microscopic characters they are closely allied, but we only offer this for what such characters are worth in such questions as these. One thing we know. This ("quartzite") granite is eruptive in its present place, and if it is part of the same formation that the adjacent granites are, then the latter are younger in their present position than the iron ore of Republic Mountain.

The preceding rocks (128, 129, 130) naturally fall under the name of *greisen*, but as they seem simply to be the modified edge of the "Laurentian" granite, we prefer to apply the name *granite* to them. The practice of giving a different name to every little local modification in rocks has been a constant source of confusion in lithology. This practice has perhaps never been carried to greater extent than it has been in this district.*

South of Ishpeming, on the line of the Chicago and Northwestern Railroad, a gray gneiss (192, 193) was seen dipping W. 33°, cut by the common reddish granite (194), which sends veins through it. Figure 26 was taken here from the side of a little cliff (195). The gneiss, at the points in which it is cut by the granite, is less schistose, and becomes more granitoid in its structure. A few rods west, on the north side of the railroad track, this granite is seen in contact (197) with and cutting a quartzite that resembles the ordinary "Huronian" quartzites. The granite is here in large masses, but shows its intrusive character when in contact with the gneiss, quartzite, or schists. About one eighth of a mile nearer Ishpeming the granite (202) was seen in contact (200) with and contorting schists (201, 203). This shows its intrusive character on both sides of the schist, the contact being well marked in many places. On the same elevation a fine-grained granite (204) was seen to be intrusive in a dark green nodular schist, containing large irregular masses of feldspar (205). These schists and granites are in the area mapped as "Huronian" by Mr. Brooks.

The granite breaking through the "diorite" at Picnic Point has been referred to (page 39). This appears to be the same as the reddish granite that occurs at the mouth of Dead River (62, 63). The lamination of this latter granite strikes S. 80° E. The reddish granite of the entire region appears to be lithologically the same. That breaking through the "diorite" at Picnic Point (56) is seen to be, under the microscope, a crystalline aggregate of feldspar, quartz, and hornblende, with magnetite. The feldspar is in part clear orthoclase, but mostly a pinkish decomposed one without definite polarization. This, according to the present imperfect method of microscopic analysis, is presumably orthoclase, but we believe it may or may not be so. This feldspar is now composed of a fibrous decomposition product, kaolin (?), with oxide of iron and quartz. Contrary to the views of Dr. Wichmann and Prof. Zirkel, we regard these as the products of decomposition of the feldspar and its enclosed foreign materials, and not originally formed products. Likewise we find the same alteration products in distinguishable plagioclase as well as in orthoclase.* The quartz occurring in the feldspar appears to be a secondary product, as also is part of that occurring independently in the rock. Many minute microlites occur in the decomposed portion of the feldspar as a secondary product. The quartz contains fluid cavities and microlites. No salt cubes were seen in the fluid inclusions. It will be remembered that Mr. Charles E. Wright pointed out that what he supposed to be the younger "Huronian" granite contained such cubes in the fluid inclusions, while the "Laurentian" granite did not. Here we have an eruptive granite in a district mapped as "Huronian" that so far reveals no salt cubes. Of course, the evidence is negative; in another section, or possibly in some overlooked portion of this section, they might be found. So long as Mr. Wright has used this as a means of diagnosis, we point to the results here simply for what they are worth to those who rely upon microscopic analysis only. The hornblende is of a green color, and is broken and torn. Considerable magnetite, pyrite, and secondary hematite was seen. Some minute crystals and grains, supposed to be zircons, were also observed, as well as secondary epidote. Titanite is quite abundant. The granite† at the mouth of Dead River (62, 63) is seen microscopically to be similar to the one just described (56). Its feldspar is not so much decomposed, and the orthoclase and plagioclase are readily distinguishable, the latter being quite abundant. The hornblende has been almost entirely altered to chlorite and biotite (?). The quartz contains microlites and fluid and vapor cavities. Some minute crystals of zircon were seen in the feldspar as well as in the quartz. The decomposed feldspar is almost filled with microlites. Epidote is abundant as a secondary product. The rock also contains magnetite.

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* See Geol. of Mich., Vol. II.

Specimen 82 (p. 52) is a pinkish-gray granite. Under the microscope it is seen to be composed of orthoclase, plagioclase, quartz, biotite, muscovite, and magnetite. The feldspar is fresher than in the preceding granites, and contains numerous mica inclusions, mostly muscovite. The quartz holds microlites and both glass and stone cavities. The muscovite generally cuts through or is mortised into the biotite, the same as the feldspar is in the augite of the diabases. The muscovite is quite subordinate to the biotite, and the plagioclase to the orthoclase. The red granite south of Ishpeming (No. 194, p. 55) is composed of orthoclase, plagioclase, quartz, viridite, magnetite, and hematite. The feldspar is somewhat altered, the plagioclase showing the same microlites and hematite alteration products as the orthoclase. Part of the feldspar shows very beautifully the polarization characters of microcline. The original mica in the rock is now altered to a viriditic material. The quartz contains inclusions of feldspar, biotite, microlites, magnetite, and fluid, vapor, glass, and stone cavities. The gneiss, in which this last granite is eruptive, is a dark gray foliated rock (192, 193) composed of biotite, quartz, orthoclase, plagioclase, magnetite, and a little pyrite. The feldspar is much decomposed, and contains microlites, as well as the lenticular, colorless foliæ, so common in the decomposed feldspars in the granites of this region, which we suppose belong to muscovite. The quartz contains the same little disks, as well as fluid and vapor cavities. Numerous microlites of apatite, as well as some grains that may belong to zircon, occur in the rock. The characters of the rock appear rather to be those of an eruptive than of a sedimentary one; but as its relations to anything older than itself were not determined, nothing definite can be said upon this point. In a section made of an intrusion of the granite through the gneiss (195), both show their respective characters as given above.

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* Geol. of Wisc., III. 601.

† Chloritic gneiss of Brooks. Geol. of Wisc., III. 662.

One half-mile southwest of Humboldt the granite is intrusive in a mica schist. The granite at this point is white, and not of the usual pinkish color. Southeast of the Old Washington mine the pinkish granite (323) was found intrusive in a hornblendic gneiss. We have termed these rocks granite because the foliation appears to be a fluidal structure parallel to the contact planes, and because they pass into regularly non-foliated granites at a distance from their junction with the schists.

Southeast of the Champion mine the granite (350, 351) is found intrusive in a schist (349, 352, 353, 354). The schist is indurated and much changed where the intrusive tongues of granite enter it (347). There can be no question that the granite is intrusive, and younger than the schists. They have both been mapped by Mr. Brooks as "Laurentian." Four hundred feet east occur his Huronian magnetic schists (348), having exactly the same strike and dip as the schists in contact with the granite. Furthermore, if we could prolong the magnetic schists in the line of their strike, so far as we could ascertain, the non-magnetic schists would be included directly in them as a component part. The difference now between the two rocks is perhaps due to the action of the granite upon the schist. Microscopically this schist (353) is composed of biotite, quartz, magnetite, and a muscovite-like mineral. The quartz contains inclusions of the other minerals, and fluid cavities with bubbles in exceedingly active motion compared with the usual rate of movement. The fluid cavities are not numerous. The part filled with quartz and the muscovite-like mineral appears to be a portion of the original fine sediment (mud) that held the coarser material. The alteration and crystallization of this argillaceous detritus give with the original quartz grains the present texture, approaching closely a gneiss.

East of the same mine the gneiss (344) was found dipping N. 60° W. 67°, and is finely foliated. This gneiss is cut through by intrusive granite, and by dikes of diabase and "diorite" (343, 345, 346). The latter cut the granite as well as the gneiss. (See page 45.) The gneiss is composed of biotite, quartz, and the same muscovite-like mineral as the schist, No. 353, which in fact it closely resembles. The quartz contains microlites, scales, and grains of the other minerals and fluid cavities. The same decomposed material cementing the quartz grains is found in this as in the schist. So far as we can tell by microscopic observation, we regard this rock as sedimentary, and perhaps only a more highly metamorphosed condition of the adjacent schist. As its relations to any rock older than itself were not observed, of course no definite statement can be made. The supposed sedimentary material forming the cement and the base out of which the mica, in part at least, has crystallized, can arise from the decomposition of feldspar crystals in their original position, and a material undistinguishable from it is seen frequently to have been formed thus in eruptive rocks. We base our conclusion that the rock is sedimentary upon the general structure of the rock, especially upon the form and relations of the quartz grains to the rest of the constituents.

The term quartzite is, we believe, when employed in its proper use, restricted to an indurated sandstone, and in this sense we employ it. We believe this to be more in accordance with the generally accepted use of the term, although, in practice, Messrs. Zirkel, Lasaulx, Hawes (a pupil of Lasaulx), and other lithologists, employ it also to designate quartz veinstones and other forms of chemically deposited quartz. Dr. Wichmann, it would seem, employed it only for rocks which have no interstitial or cementing substance remaining uncrystallized between the quartz grains. He classes them under the head of non-fragmental rocks, saying that his other class comprises all those "which have been formed mechanically out of the materials of older rocks," yet he describes a quartzite that he regards as having been a fragmental rock. In fact, his lines between fragmental and non-fragmental rocks seem to have been drawn from the realms of fancy, as a large proportion of his non-fragmental rocks are evidently, both from field and microscopic characters, as truly sedimentary as those classed as fragmental ones. If we understand Dr. Wichmann aright, we presume that the St. Peters sandstone when indurated, as we have frequently seen it, would form a quartzite, while the Potsdam sandstone, if it were indurated in like manner, would form a — sandstone, unless some of it had its cementing material entirely crystallized.*

The reddish and grayish quartzite, near the northern railroad track west of Ishpeming, is composed of quartz in rounded grains held by a chloritic cementing material. Considerable hematite was observed as a decomposition product. The quartz contains microlites, trichites, and fluid cavities. The quartzite forming the *fallen* wall of the New York mine (186) is a very dark greenish-gray rock, composed of rounded grains of quartz, and crystals and fragments of magnetite cemented by a chloritic material. The interstitial substance in this appears to have been entirely changed to chlorite. The quartz contains microlites, trichites, and fluid inclusions more abundantly than the rock last mentioned. A fragment of jasper was observed in this rock. Another specimen of the same rock (187) is composed of macroscopically evident fragments of jasper and magnetite, and quartz grains. Under the microscope the section was seen to be composed of quartz, jasper, magnetite, and chlorite. The quartz has the same inclusions, but part of the microlites appear to be zircon. These rocks, as we have before pointed out, were evidently derived from the underlying ore-bed (page 30).

The quartzite (197, 198) found to be older than the intrusive "Laurentian" granite (page 55) is a dark gray rock composed of quartz grains, biotite, and fibrous microlitic cementing material. The quartz contains fluid inclusions and little crystals of zircon. The crystals of zircon are the same as those observed in the gneiss in that vicinity (193), and it is not improbable that the quartzite is derived from it. In this case the order of succession is, 1st, the gneiss; 2d, the quartzite; 3d, the eruptive red granite (gneiss of Mr. Brooks).

The quartzite overlying the ore at the north pit of the Jackson mine at Negaunee is made up of the ruins of the underlying ore. It is composed of quartz, jasper, magnetite, hematite, and a fibrous microlitic interstitial material. The quartz contains microlites and fluid inclusions.

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* Geol. of Wisc., III. 613, 615, 649, 655.

The rock through which the "diorite" (page 43, No. 232) passes, is a highly indurated feldspathic sandstone (233), in which the feldspar predominates greatly over the quartz. It has a greenish, compact, felsitic base, holding grains of quartz. This would easily pass for a quartz porphyry or felsite, with those who advocate the passage of sedimentary rocks into felsite. It is best classified as a *porodite.*[*] Microscopically it is seen to be composed of fragments of feldspar with some quartz grains. The feldspar is decomposed greatly, forming micaceous scales, but shows in some cases its triclinic character. It was most probably formed from the detritus of a granite.

Potsdam Sandstone.

The sandstones at Marquette resting upon the azoic schists are in the upper portions fine-grained (14, 15), but below they become conglomeritic. The coarser sandstone (12 A, 13) is composed principally of quartz and feldspar; the feldspar is the pinkish variety belonging to the azoic granites in the vicinity. Many of the quartz grains are seen to be crystals with unworn facets; it is therefore probable that they came from veins, and the sandstone making was quite rapid. The other sources of the quartz were probably the granites and quartzites underlying them. Coarse pebbles occur in portions of the rock belonging to the adjacent formations: quartzite, ferruginous quartzite, argillite, chlorite, "diorite," etc. (16, 17, 18, 19, 20, 21, 22, 23, 24, 25). The inclosed pebbles were evidently when deposited nearly, if not quite, in the same condition as they and the rocks from which they were derived are to-day; as was pointed out by Foster and Whitney. South of the Carp River, in the locality figured by Messrs. Foster and Whitney, the sandstone strata are seen to abut against and overlie the vertical edges of the quartzite (29, 30, 31, 32, 33, 34). The dip was about S. 20° W. 16° to 18°. The Sandstone at Presque Isle contains the same materials as that south of Marquette, but has suffered a local modification described in connection with the peridotite of that point; — to which we now pass.

Peridotite and Serpentine.

The chief rock at Presque Isle, north of Dead River, is a peridotic one, composed of olivine, enstatite, and diallage, which is the composition

[*] Bull. Mus. Comp. Zoölogy, V. 280.

of lherzolite. In places, this rock is much altered, forming a serpentine (65, 66, 67, 68, 69, 70, 71, 72, 73, 74). We find every gradation, from the rock only partly altered to that which is so completely changed to serpentine that only traces of the enstatite, diallage, and olivine remain.

Under the microscope, the rock (65) is seen to be made up of rounded grains and crystals of olivine, held in and often completely surrounded by the enstatite and diallage. These minerals evidently crystallized later than the olivine, and play the same *rôle* here that the augite does in diabase, the glass in basalt, and quartz in granite. The olivine is traversed by fissures, along which the usual serpentinous alteration has taken place. In many, the alteration is confined to the vicinity of the fissures and the periphery of the olivine, but others are changed throughout. Much black dust comes in the altered portions (magnetite?), as a residue left over in the decomposition of the olivine and the formation of the serpentine. In many cases this black residuum forms a rectangular or irregular network or grating throughout the changed olivine. The enstatite is altered along the cleavage planes and network of fissures by which it is traversed. It does not become changed to the serpentine so readily as the olivine. All contain inclusions of black octahedral crystals that are presumably magnetite, as the powder is magnetic, and no trace of chromic oxide was found by chemical tests. Besides the serpentine, there occur, as other alteration products, feldspar (?), viridite, and dolomite (?). The hand specimen (65) is a grayish black (almost black) rock, showing under the glass a little serpentine, enstatite, and magnetite. It weathers somewhat brownish.

In other specimens from the same rock, but more altered, we only find traces of the original structure. The formation of the serpentine along the fissures, and the network of magnetite, usually are well marked after the enstatite, diallage, and olivine are entirely altered. The serpentine, unless it suffer alteration itself, generally shows under the microscope its original structure, as it was formed along the fissures. One section (71) shows simply greenish pseudomorphs after olivine enclosed in a carbonate, presumably dolomite. Another section (74) is composed now of serpentine and magnetite, and, if it were not absolutely known whence it came, its derivation could only be told by the arrangement of the magnetite. Certain of the specimens are largely composed of the dolomite observed in No. 71, and microscopic as well as field examination renders it most probable that Dr. Rominger's stratified dolomite (72) is simply a more highly altered portion of the peridotite. No. 71 came from the east side and out of the same upper formation as No. 72. This is a reddish brown and greenish serpentine, traversed by a fine network of dolomitic veins. The microscopic characters of the decomposed peridotite were given to some extent by Dr. Wichmann, who, it would seem, had only the serpentine, under which name he describes the rock.*

The geological history of this rock is very interesting. Dr. Houghton thought that it was an eruptive rock, and younger than the sandstone which was uplifted by it, believing it to be a greenstone impregnated with serpentine. He states that, near the line of junction, the sedimentary rock has been greatly shattered, and its fissures filled with injections of calcareous matter. Dr. John Locke thought the "light green trap" was interfused with the sandstone at this point.

Messrs Foster and Whitney considered that the rock was an immense consolidated lava flow, although it wanted the vesicular structure, while the part filled with the white veins was regarded as a volcanic sand or ash deposited on the lava stream. Younger than this azoic lava was the sandstone deposited upon it (Potsdam). Chemical analysis was given of it, but no name assigned to the rock. Later, this was regarded as closely related to serpentine by Professor Whitney, who gave three analyses of it.† Later, Dr. Hunt, accepting Professor Whitney's analyses, regarded this rock as a somewhat impure sedimentary serpentine belonging to the Huronian series.

Dr. Rominger later regarded this rock as a half-decomposed basalt or highly ferruginous serpentine; the part filled with the veins was taken to be an older sedimentary rock, a dolomite, upheaved and broken by the trap, and overlaid by the conglomerate and sandstone. This sandstone is supposed to have been deposited in the inequalities of the underlying rock following its contours. He thought it most probable that the sandstone was deposited at its present inclination, although it may have been slightly upheaved since. The conglomerate beds at the base of the sandstone are said to contain numerous fragments of the underlying rock. We regard this peridotite as an eruptive rock, younger than the sandstone overlying it, and agree in this particular with Dr. Houghton. The portion filled with veins, that was taken by him as a sedimentary rock belonging to the sandstone, or a mixture of sandstone and trap; as a volcanic sand or ash, by Messrs. Foster and Whitney; and as a dolomite, older than both the trap and sandstone, by Dr. Rominger,— we regard as simply the upper portion of the intrusive mass modified by its contact while heated with the overlying sandstone, and by the percolating waters since.

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* Geol. of Wisc., III. 619.

† Am. Jour. Sci., 1859, (2,) XXVIII. 18.

As we differ so strikingly in most particulars from the geologists quoted, it is necessary to give our reasons therefor. Only part of a day could be spent at Presque Isle; therefore, many things that ought to have been examined could not be. On the southeastern side, the sandstone dips quite irregularly from twenty to thirty degrees southerly. The strata follow the curve of the underlying peridotite, forming in places anticlinals. The distinction between the sandstone and its underlying rock was everywhere seen by us to be well marked. The surface of the peridotite is in rounded knobs, the whole mass itself in general outline forming one immense knob. The sandstone and conglomerate were examined, and found to conform in their stratification to the contour of the whole mass, having the same waving outline; also, for from two to three feet above the peridotite, they are indurated, changed, and show characters that we regard as evidence of heat action and of hot waters. They are filled with vein and chalcedonic quartz, and hardened and reddened the same as is the sandstone immediately underlying the melaphyr overflows in the Copper district (75, 76, 77, 78, 79). Certain portions have been changed, so that they resemble a volcanic ash, although they are simple ferruginous sandstones (78). Above the limit of baked sandstone and conglomerate comes the unaltered ordinary red sandstone (81). Microscopic sections of the indurated conglomeritic sandstone show that much of the quartz is a secondary water deposit since the deposition of the fragments composing the rock. We searched carefully for the pebbles or fragments of the underlying rock in the conglomerate, which Dr. Rominger states are abundant, but could find none. We have been unable to find either macroscopically or microscopically a single trace, so far, of the peridotite or of its veined portion (dolomite of Rominger) in the conglomerate or sandstone. The peridotite forms abundant pebbles now upon the beach, which, had the conglomerate been formed upon it, should have been included. The conglomerate and sandstone contain the same material in pebbles, etc. that the sandstone and conglomerate do in the Marquette quarries and near Carp River. Had the sandstone and conglomerate been laid down upon the irregular surface of the peridotite, they should have abutted against its unconformable portions, the same as they do against the quartzite at Carp River; instead of this, the strata conform to the curves of the peridotite, like layers of blankets, forming anticlinals and synclinals. The dip in many places, especially on the southeastern side, is too steep and irregular, while the strata are continuous, to have been formed at that angle by sedimentation. The induration of the sandstone and conglomerate, and of the enclosed pebbles, as well as the deposition of the silica, do not occur where the sandstone has been seen to come in contact with the "Huronian" schists and quartzites. From the above facts we feel that we are justified in dissenting from the views of most of those who have written upon this locality.

At the eastern portion of Presque Isle, either a fault or a protrusion of the peridotite up through the sandstone exists. This locality we were able to examine only a minute or two, on account of an approaching thunder-storm, while we were in a row-boat, but it deserves further careful examination. The best serpentine that we saw upon Presque Isle was observed at this place. In the thin section, the more serpentinous portions of the peridotite are frequently seen to contain dolomite, and fragments effervesce freely in hot hydrochloric acid. The upper portion, supposed to be dolomite by Rominger, extends as a sheet of variable thickness over all the peridotite separating it from the overlying sandstone. This, so far as we can tell, is the upper portion of the peridotite, affected by direct contact with the sandstone, and by the action of hot waters since, at the time the silica was deposited in the conglomerate. This part is filled in with impure dolomitic veins, which, it seems, caused Dr. Rominger to pronounce the rock a dolomite, although the veins have the characters of being secondary water deposits, as they were described by Messrs. Foster and Whitney, and not igneous injections, as they were thought to be by Dr. Houghton. The unmistakable peridotite has in places the same structure. The peridotite is much fissured, breaking up into rounded masses, cemented by segregated serpentine. We regard the peridotite as eruptive, and feel that its field and microscopic characters both point to the same conclusion. The manner of eruption was probably something like the laccolites described by Mr. G. K. Gilbert; on the sides the strata were arched and bent upwards, but on the eastern end either a fault or protrusion exists. This place would afford an excellent chance to study the relations of the sandstone to the peridotite, if the contact of the two can be seen.

If we are right in our observations and conclusions, this locality has an important bearing upon the origin of the serpentine here, showing that it is a metamorphosed eruptive rock, and of younger age than at least some one hundred feet of the sandstone. It further shows that, so far as this is concerned, lithology fails in giving the age of a rock, this having been indorsed as good "Huronian";* also that an eruptive rock may be so changed as to be taken by observers for a sedimentary stratified one, even a good dolomitic limestone. The origin of the serpentinous part by direct change *in situ* of a peridotite (eruptive), as well as by the filling of fissures in the peridotite by serpentinous material derived from the surrounding rock, would seem in the main to be consonant with the observations of Bonney, Becke, Berwerth, Dathe, Doelter, Drasche, Hochstetter, Koch, Lemberg, Sandberger, Streng, Tschermak, Zirkel, and others. Peridotite, which we provisionally classed with gabbro under basalt, in a preliminary publication "On the Classification of Rocks,"* it would seem from further and more extended study, should be classed as a distinct species; and some other rocks may possibly belong with it. This species would represent a more basic one than basalt, containing generally between thirty-five and forty-five per cent of silica, or, more nearly, forty to forty-three per cent. The reasons for this view it is intended to give fully in another publication, but they would be out of place here.

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* Mr. Brooks thinks "it is not certain that this is of Huronian age." (Geol. of Wisc., III. 659.)

The following analyses (incomplete) of this peridotite were made and published by Prof. Whitney : —

	I.	II.	III.	IV.
SiO_2	38.24	36.95	37.25	
Al_2O_3	1.48			
Fe^2O_3	34.50	16.50	6.75	12.90
FeO			14.14	19.52
MgO	14.83	33.07	28.67	14.83
CaO	1.42			
Na_2O	Determined with the iron.	.97	1.16	
H_2O	9.53	10.40	10.89	
	100.00		98.86	

Analysis I. is taken from Foster and Whitney's Report on the Geology of Lake Superior, II. 92. Analyses II., III., and IV., from the American Journal of Science, (2,) XXVIII. 18.

Three miles and a half northwest of Ishpeming, or one mile and a half west of Deer Lake, serpentine occurs abundently on the land of Mr. Julius Ropes, postmaster of Ishpeming.† This rock, although quite hard, forms very beautiful specimens when polished (234, 235, 236, 237,

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* Bull. Mus. Comp. Zoölogy, V. 279.

† First Annual Report of the Commissioner of Mineral Statistics of the State of Michigan, pp. 204 – 206.

238, 239, 240, 241, 242, 243, 244, 245, 246). Associated with and comprising probably part of the same formation is a greenish and grayish limestone (247, 248, 249, 250, 251). In one place much chrysotile was seen, which had formerly been regarded as asbestus (252).

No. 235 is a beautiful green serpentine, giving a colorless section holding magnetite. Under the microscope this shows a most beautiful fibrous aggregate polarization. Other sections (241, 242, 243, 245) show a more coarsely fibrous aggregate polarization, and are composed of serpentine and magnetite. The magnetite is seen here to be arranged in the same way that it was in the more decomposed peridotite of Presque Isle, forming a network corresponding to the outlines of the grains and fissures in the olivine, as well as occasionally a network in the altered olivine itself. Although we find no trace of either olivine or enstatite in this serpentine, this structure gives a strong probability that this rock was originally in nature and origin a peridotite. Every microscopic character in this serpentine indicates that it is formed by direct alteration *in situ* from another rock, and, so far as we can now tell, that was an olivine one. Whether this is of the same age and origin as that at Presque Isle or not can only be determined, if at all, by studying its relations to its associated rocks.

General Discussion and Results.

The historical part of this paper we have endeavored to bring down to the date of its completion. As the historical portions of both the Iron and Copper districts were, in the main, written in 1879, the latter material has been added as best it could be done. On March 6, 1880, through the courtesy of Prof. T. C. Chamberlain, Chief Geologist of the Wisconsin Survey, we received an advance copy of that portion of the third volume of his survey publications which gives Dr. Arthur Wichmann's microscopic analyses of some of the rocks in the Iron district and Appendices A and B, or from pages 600 to 663. This detached portion has been referred to repeatedly in the preceding pages, but no connected account was or need be given of it. On April 8 the complete volume was received, but as the preceding portion of our work was, with the exception of a few pages, already prepared for the press, and in part struck off, it became necessary to incorporate all mention of it in this portion of the paper at this date (April 10, 1880).

The observations and figures given in the preceding text show conclusively that the statements of Messrs. Dana, Kimball, Hunt, Brooks, and others, that the iron ore is interstratified in the associated schists, are incorrect, and only return to the view advocated by Mr. Foster in his early publication. So far as geological science has now advanced, the facts observed can only be explained by the eruptive origin of both the ore and jasper, as they make the same formation. The only escape from this conclusion is the supposition that the ore and jasper have been rendered plastic *in situ*, while the chloritic schist has not been. Such a supposition Mr. Brooks was forced in part to adopt.* That the ore and jasper have been thus rendered plastic, while the schists, quartzites, and other associated rocks have not been, is too absurd, chemically or geologically, to be tolerated for a moment as an hypothesis. Should it or any other theory be proved to be correct in actual fact, then it is to be admitted; but when one resorts to theories that are not sound scientifically, merely to escape from a dilemma that a former theory brings him to, he is neither philosophical nor scientific. Theories must conform to facts, not the facts to the theory. We can point out facts whether they can be explained or not, but the theory must conform to our present knowledge. The ore and jasper show that they are the intrusive bodies by their breaking across the lamination of the schists and other rocks, by the changes that take place in the latter at the line of junction, by horses of schist being enclosed in the ore, by the curvature of the lamination produced by the intrusion of the ore and jasper, etc. Not the slightest sign of the plasticity or intrusion of the schists relative to the ore or jasper was seen. That the present lamination of the schist existed prior to the intrusion of the ore and jasper is shown by the effect of the latter upon and its relations to it. That this lamination is the original plane of deposition is for part of the schists not known; but whether it is or not, it has been taken to be such by the observers quoted in the establishment of their theories, and they must abide by it. The lamination, however, coincides with many of the well-stratified rocks adjacent, and in some of these the ore and jasper were unmistakably intrusive. The schists that retained well-marked stratification planes showed in some places extraordinary contortions, one specimen (293) showing a synclinal and anticlinal fold, requiring, were the top eroded, the counting of the same layer four times in the width of two inches. This is only one case out of numerous ones observed (292, 292+, 302). In the fine-grained detritus composing some of the schists it is quite likely true that the lamination does not coincide with the original bedding; but if it does not, then the breaking of the ore across any chosen plane whatsoever, except the lamination plane, can be shown more easily than in the former case.

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* Geol. of Mich., I. 139, 140.

The ore and jasper seem to have been erupted in huge bosses and overflows, as well as intruded into the schist in the form of long arm- and wedge-like masses or sheets. On account of the banded character of the jasper, and the intrusion generally being nearly in line of the lamination in the large mass, they have an apparently stratified character to those who believe any "striped" rock is a sedimentary one; but when examined in detail, and in places where the relations can be seen, they prove to be eruptive. Those who advocate the sedimentary origin only, take the jasper and ore as a whole, and, because it is apparently to them stratified, assume without further question or examination that it is so. We have gone upon the principle, that the relations of rocks to one another show the origin of each one except the oldest, and this must be the arbiter in every case when the other characters are doubtful or are questioned. It happens then that this is largely a question of methods and principles of observation.

The natural work of mining is to obscure or destroy the geological evidences; furthermore, the natural changes that have taken place in the constitution of the rocks, the decomposition, the uplifts, fractures, foldings, and other accidents which they all have suffered, tend to increase the difficulty of finding such proof. Of necessity the characters show best upon the walls of abandoned open pits which the rain had washed clean, but they were also found in the present workings. Likewise they are best studied in comparatively small masses, partly because their relations are easier seen, and partly because the miner generally leaves no others that can be studied. We were enabled, however, to observe the intrusive relations, not only of small masses, but of some containing thousands of tons. The small masses were, however, either seen to be joined, or had been joined until cut off by mining, to the main body. The view that they have been rendered plastic *in situ* is not sustained by the facts, and when we take into consideration the associated rocks is absurd on its face. The facts, then, sustain the views and observations of Messrs. Foster and Whitney, and show that the work of the other observers has been superficial and inaccurate. We are well aware that objections from a metallurgical or chemical standpoint have been raised against the theory of the eruptive origin of hematite and silica together, in such forms as we now find them. If the ore was magnetic at the time of eruption, and has since been altered, this objection is then done away with. The secondary changes that have occurred in the rock since eruption, as shown by microscopic examination, may also help. It is well known that there are facts in every science that it is not able to explain at any one given time; but the facts exist the same, and the science in time rises to meet them. So in this case the fact is they are eruptive, and the burden of chemical explanation rests upon the chemist, not upon us. He must explain it sooner or later, unless he disproves our observations. Crystals of hematite crystallizing from the molten magma of trachytes and rhyolites have long been known, and are described in all the standard works on micro-lithology. These then offer the same problem, and prove that hematite can be crystallized directly out of the same molten magma, and at the same time with the silica and silicates. It is the business of the chemist to meet the facts, and not for us to make the facts conform to his knowledge or theories. It is our business to state what we see and find, and his to explain it if he can, but not to deny it for the simple and sole reason that he cannot cope with it in the present state of his knowledge. The eruptive origin of the iron also has a bearing on the theory that its presence indicated a vast amount of organic life in the "Huronian" epoch.

We have found that a large proportion of the rocks said to be interstratified, and to pass by insensible (or any other) transitions into the adjacent rocks, are eruptive, and do not so pass into the country rock. The assumption that they were stratified was based on their foliation being parallel to their walls, on their being intrusive approximately parallel to the lamination of the schists, their general resemblance to the country rock of similar chemical composition, the inability of the observers to find their lines of junction, and the lack of knowledge of the same observers of the characters of eruptive as well as of sedimentary rocks. Their decision in this, as before, was based on a mere superficial glance over the surface, and the assumption that, because a rock looked as though it was stratified, i. e. had any marks that they thought indicated stratification, it must of necessity be stratified. No effort was made to find out the real relations of the rocks to one another. No attempt was made to see whether one rock was laid down on another as a sedimentary bed, or whether it was an overflow or intrusion. They were "striped" or foliated, jointed or showed cleavage planes, and that was enough; any further observation was superfluous. They assumed that Messrs. Foster and Whitney's work was erroneous without making the necessary observations to prove it so, and the geological world accepted it without question because it agreed with the fashionable theories.

The intrusive rocks belong in general to the basalts, but are of course old, and in the majority of cases greatly altered. One probable andesite as well as intrusive felsites (rhyolites) was discovered. These rocks had never been noted before by the previous observers. One class of the intrusive rocks can be referred to the basalts only with doubt, as the necessary proof of their original composition is thus far wanting, i. e. the actinolite rocks. The evidence is very strong that in the other basic intrusives all the varieties are produced by the alteration of their constituents, and that they were not erupted in their present state.

It is to be noticed that, while we have found olivine abundantly in the diabases, Dr. Wichmann states that "olivine diabase is not present amongst the rocks from the iron region of Lake Superior." *

The "soft hematites" are doubtless produced by the decomposition of the jasper and its ore, brought about by the fracturing of the rocks by the intrusives and by the secondary action of water, presumably hot, on account of the microscopic characters of the quartz deposited by it. Besides the "soft hematites" there occur the quartzites and conglomerates derived from the ore and jasper, as well as the sandstones and schists impregnated by iron, which are sometimes mined to a slight extent.

We have heretofore seen that the view that the "Huronian" unconformably overlies the "Laurentian" has been only supported by the fact that the foliation of the latter did not conform in its dip to the lamination of the former. This proof is of no value unless it can be shown that both rocks are stratified and *in situ.* That the latter is not so, we have seen in numerous localities. Heretofore the two systems have not been observed in contact, but recently statements have been published that their junctions have been seen in other regions.† The statement is made that both rocks are stratified, but no proof is adduced to show on what the conclusion is founded, and, although the contacts were said to show beautifully, nothing was published indicating that the kind and manner of the junction was observed. It would seem that even here the decision concerning the unconformability was based on the foliation only.

So far as the Marquette district is concerned we have shown very much stronger and more abundant evidence to prove that the "Laurentian" granite is younger than the "Huronian," and an eruptive rock, than has been advanced by Mr. Brooks (the only one who has advanced anything called proof) to show that it is older. Further, the inability of the later observers to distinguish the eruptive rocks, even in the "Huronian," detracts from their evidence concerning the "Laurentian." The granite that Mr. Brooks placed as Formation XX. of the "Huronian," merely because that was the easiest way to dispose of it, unless he wished to acknowledge that his "Laurentian" granite or gneiss was intrusive in the "Huronian," bids fair to absorb now all the "Laurentian" region, if we can judge from what Mr. Brooks writes. He says: "Dr. Rominger considers certain granitic and gneissoid rocks north and southwest of Marquette, which I did not study but regarded as Laurentian, to belong to this series. I have but little doubt but that the younger Huronian rock made out in the Menominee region (the granitic bed XX.) will yet be identified in the Marquette region, and will be found to be more or less gneissic. The very rocks mentioned above may possibly be Upper Huronian; the granites, etc., southwest of Michigamme lake very probably are."* Although this granite is in the region mapped as "Laurentian" by Mr. Brooks, he does not tell us how to separate it from the "Laurentian," or where the dividing line is to be found. How does he know that it is not the same as the other "Laurentian" rocks? He has never made any examination to see whether it is or not, and in the above-quoted remark of his he virtually acknowledges that he knew nothing of the rocks that he mapped as "Laurentian" in the district since examined by Dr. Rominger.

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* Geol. of Wisc., III. 627.

† Ibid., III. 98, 108, 117.

We tried to find some point where we could trace rock continuously from well marked and mapped "Laurentian" into the "Huronian," but were unable, with the time and opportunity at our disposal, to do more in that direction than we have already pointed out. The evidence is strong, but not so conclusive as we could have wished; yet what would it have availed us if we had found such a locality? We should have been told: "Oh! that is Formation XX. that you found; we knew nothing about the region, so we mapped it as Laurentian." May we suggest that hereafter geological maps of Lake Superior be colored as "Huronian," and "Formation XX."? Let us substitute the last term for the "Laurentian" at once, and have done with it before Formation XXII. is born. At another locality, the granite that Mr. Brooks assigns to "Formation XX." Professor Irving places under the "Keweenawan."†

While at Lake Superior the followers of Dr. Hunt thus place a troublesome granite cutting the "Huronian" as the latest formation in it (except one), in Eastern Massachusetts a granite said to cut and to be intrusive in the Primordial slates, as well as in the "Huronian" so called, is for this reason placed by them at the base of the "Huronian." Furthermore, the diabases that are intrusive in all, even the youngest rocks known here, are for that reason considered to be the equivalents of the "Norian," and regarded as older than the "Huronian." Now, if the granites are intrusive in the Primordial or Braintree slates, as we know the felsites are intrusive in the granites, and as we know the diabases are in all, we naturally should, as we have done, regard these rocks as crystalline eruptive ones, owing their crystalline character to crystallization from the molten magma, and geologically younger than the Primordial, i. e. Palæozoic rocks. But we see now that we were mistaken. Why not go to the Cordilleras and say of the basalts, These are "Norian" or "Naugus Head"; of the rhyolites, These are "Huronian"; of the trachytes and nevadites, These are "Laurentian," or "Formation XX."; of the andesites, —— ? Why not station one's self by a volcanic crater, and determine, as the eruption takes place, whether Formation V., XV., or XX. is rushing by ?

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* Geol. of Wisc., III. 529, 530.

† Ibid., III. 193-195.

It seems, then, that in different localities different methods of interpreting the same facts are resorted to, but for the same purpose and result, — the rocks come out "Huronian" every time. Taking into account the methods pursued; the hypothesis, yet unproved by any careful, accurate work, that lithological evidence is conclusive; the assumption that foliation, banding, etc. of necessity prove stratification; the practice of inserting faults in the formations wherever it becomes convenient to do so in order to carry out the theory; that Dr. Hunt, in order to sustain his views, has, in Eastern Massachusetts, directly stated that the granite cuts the felsite, when the reverse is exactly the case, dike after dike of the latter cutting the former, as pointed out by us before,* and since most conclusively shown by Mr. J. S. Diller; † that the Norian rocks are probably in all cases eruptive basaltic rocks (gabbros); that the Keweenawan system has no foundation except in erroneous observation, as it conformably overlies the Potsdam sandstone, as we shall show later; — taking these and other things into consideration, we feel that the very basis on which the Laurentian, Huronian, and other such geological epochs were established, is yet an open question for discussion. Even in Canada the evidence is very far from being clear that the relations of the Laurentian and Huronian are what they are supposed to be. The agreement of hundreds of geologists in every quarter of the world does not establish anything, if that agreement is based on the same theories and methods, unless the theories and methods are correct. The evidence is clear enough in New England and at Lake Superior that the theory is unproved, and the methods and observations incorrect or superficial. It seems to us that a striking commentary on the value of lithological characters is afforded in the Marquette district by the letters and the comments upon them given on pages 657 to 660, inclusive, of the third volume of the Geology of Wisconsin.

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* Bull. Mus. Comp. Zoöl., V. 282.

† Proc. Bost. Soc. Nat. Hist. XX., 354.

We frequently are informed that microscopic analysis will make up for all deficiencies in field work; that one can tell in this way whether a granite or any other rock is eruptive or metamorphic; that Formation XX. is to be distinguished in this way from the Laurentian granite, etc., etc.*

The study of rocks microscopically enables us to investigate their structure, constitution, and alterations, — the structure of their constituents and the various relations that these bear to one another, as well as the order of their formation. It gives us the internal history of a rock more or less complete, — a thing that no other known method will do. It enables us to tell the species, arrange, and generally to classify our rocks. With the exception of such as are greatly altered, it enables us to distinguish the fragmental from the non-fragmental forms. When we are familiar with the microscopic characters of unchanged sedimentary rocks and of unaltered volcanic ones, they having been known to be such from field evidence, we have a basis for recognizing rocks, concerning whose field relations we know nothing, as belonging to one or the other of these classes, the same as by the unaided eye we recognize a coarse granite or conglomerate. This of course only applies to rocks concerning whose nature and origin there is no dispute; or to those which under the microscope show such undoubted evidence of their origin that it cannot be rejected. If a rock is clearly seen under the microscope to be made up completely of fragments, no one would doubt that it was a fragmental rock, even if it looked to the unaided eye as though it were a non-fragmental one. In like manner, when a rock has the microscopic characters of an eruptive one, we feel that it is right to regard it as such, even if it was *supposed* (not proved) to be a sedimentary one by the collector in the field. Both of these are of frequent occurrence in the work of a lithologist. Take now the great intermediate class of rocks, those that are so altered that their original characters are greatly or entirely changed, and the case is different. We can only proceed in safety when we know their field relations, or those of rocks that are like them. In order to know the microscopic characters of a sedimentary granite (if such a rock exists), it is necessary to study one that is known beyond question to be sedimentary, and to compare it with the most highly altered eruptive ones known. By this method of proceeding, always taking as the basis rocks whose relations to their fellows were known, diagnostic points of great value would be found, and a more just idea of the relations of the fragmental and non-fragmental forms obtained. The field evidence would have to be the arbiter in all cases. If a rock is eruptive, or if it is sedimentary, it is so, whatever may be its microscopic characters. In this class of rocks lithology is at present weak, and assumptions take the place of facts.

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* Geol. of Wisc., II. 73; III. 194, 255.

Although in no case in this paper have we attempted to give any elaborate microscopic analyses, but only a few of the more general facts, we have shown plainly enough the fallacy of determining the geological relations of highly altered rocks by microscopic analysis alone. Any one who takes pains to read pages 533 to 599, inclusive, of the third volume of the Geology of Wisconsin, will doubtless be convinced that different observers, under the present method of microscopic analysis and classification, reach widely different results in the study even of the same specimens. He can further compare our description of the Picnic point rocks with that given on page 567, and also with Mr. Brooks's statement that granite dikes "have never been observed in the Marquette series" (*l. c.*, p. 452). It is of course worthy of remark, that of the lithologists who have microscopically studied the rocks of Lake Superior, Messrs. Pumpelly, Wright, Irving, Hawes, Rutley, Julien, Törnebohm, and Wichmann, not one, so far as we can learn, had at that time any especial personal acquaintance with the characters of modern unaltered eruptive rocks, except possibly the two last named. Yet it is essential that one should be thoroughly acquainted with the unaltered forms of rocks before attempting to solve the most difficult lithological problems on the globe, i. e. those relating to the altered forms. As descriptions of what these observers saw in the individual specimens examined by them, their work is undoubtedly of great value; but beyond that there is a great chance for differences of opinion concerning their conclusions, or the basis upon which these were established.

The sedimentary rocks of the Marquette district generally give evidence of being shore deposits, and although they may have been deeply buried under later formations, yet in themselves we consider that they give no evidence of it.

The general structure of the country would seem to be as follows. The schists, sandstones, etc., having been laid down in the usual way, were then disturbed by the eruption of the jasper and ore; this formed the knobs of jasper, the banding belonging to the fluidal structure, and not to sedimentation. Besides occurring in bosses, the jasper was spread out in sheets, and intruded through the rock in wedge-shaped masses, sheets, and dikes. Much of the original rock still remained horizontal, and new sedimentary deposits continued to be formed out of the jasper and the other rocks. Next came the eruption of "diorite," which completed most of the local folding and tilting of the strata. Finally, the granite eruption took place on both sides of the "Huronian," uplifting and contorting the strata near it, and perhaps laterally compressing the enclosed iron-bearing rocks. No basis exists so far, then, for the scheme of formations laid down by Mr. Brooks, as it was founded on the supposition that all the rocks were sedimentary. The other results of our work are: the showing more clearly the age, origin, and nature of the peridotite at Presque Isle, and the formation of serpentine from it *in situ;* the finding of ottrelite schist as a metamorphosed rock from the ordinary schist; the showing that tourmaline and olivine are more abundant here than heretofore known; the finding of granite and felsite within the Marquette district, etc., etc.

Concerning the serpentine (peridotite) of Presque Isle Mr. Brooks remarks, "It is probably Huronian, and presents some of the phenomena of an eruptive mass." * Later he says, "It is not certain that this is of Huronian age." †

Although in deference to the common custom we have employed the term *jasper* in writing of the silicious eruptive rocks associated with the ore, in reality it is not properly called so. It is often uncolored, and has then generally been designated by observers as a quartz schist, they believing it to be sedimentary. The rock further has been denominated felsite or petrosilex, but physical and chemical characters remove it from these old rhyolitic rocks. It is more acidic than the rhyolites, the silica being above eighty per cent. We also found other eruptive rocks of like acidic character, and, so far as our observations have now gone, it seems probable that rocks of this class are much more abundant than we should at first suppose. They would naturally be taken at first sight for quartz schists, quartzites, and other sedimentary rocks, and no further investigations be made to ascertain their relations to the associated rocks. We would propose, therefore, that all the acidic eruptive rocks, whose chemical and physical constitution carries them above the rhyolites, should be designated as *Jaspilites* from ἴασπις and λίθος in accordance with a suggestion of Professor Whitney.

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* Geol. of Wisc., III. 532.

† Ibid., 659.

Finally, so far as our work has gone, it shows that Messrs. Foster and Whitney were right in their observations and conclusions, so far as it relates to the geological structure of the country, or to the origin of the rocks and ores, except the peridotite. To them and to them alone belongs the credit of having done their work accurately, and as thoroughly as the circumstances would allow, while the more recent observers and writers, Kimball, Credner, Rivot, Hunt, Dana, Brooks, Lesley, Winchell, Newberry, Wright, and others, have held and pushed theories in direct opposition to the facts, until a geologist who took a different view was regarded either with pity or derision. As regards the general geology of the country, we feel that Messrs. Foster and Whitney's writings remain to-day the best and most accurate exponents. Considering the difficulty of exploring the country thirty years ago compared with the present, it is surprising how much they saw, how accurate their observations were, and how little has been added to our knowledge since; also how our knowledge and science have again retrograded, until geologists have gone back to the views of Messrs. Houghton, Hubbard, and Locke.

The Copper District.

The earliest writer to advance any especial views regarding the copper and its origin, so far as we are aware, was Henry R. Schoolcraft.* He considers it probable that the masses of copper about the Ontonagon River were thrown out of volcanoes by volcanic action. The mountains are said to be of granite (Porcupine Mountains) so far as observed, and the sandstone to have been upheaved into a nearly vertical position at their base by the elevation of the granite. He considers that native copper will never be found in sufficient abundance to pay for mining, but that probably "valuable mines of the sulphuret, the carbonate, and other profitable ores of copper," will be discovered.†

In 1823, in describing a supposed vein of malachite on Keweenaw Point, he concludes "that the entire peninsula consists of a spine of granite, with sandstones, amygdaloid, and secondary trap, deposited around its base." *

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* Am. Jour. Sci., 1821, (1,) III. 201-216. Quart. Jour. Sci. and Arts, London, 1822, XII. 422, 423.

† See also Senate Papers, 2d Sess., 17th Aug., 1822, Doc. 5.

Dr. John J. Bigsby regarded the Lake Superior sandstone as being most probably of the age of the Old Red.† Commander H. W. Bayfield, in his paper entitled "Outlines of the Geology of Lake Superior," ‡ regards the hills of Keweenaw Point as formed of syenitic granite, of the same character as that at Granite Point, and opposes the idea that the first-mentioned point is an amygdaloid district. He regards the trap and granite as the prior formed rocks, and that the sandstone is composed of their *débris.* This sandstone, which he takes to be Old Red sandstone, is said to have been tilted by a secondary upheaving, or subsidence of the granite.

In Dr. Douglas Houghton's report on the copper of Lake Superior to the Secretary of War,§ we find the following statement: "After having duly considered the facts which are here presented, I would not hesitate to offer, as an opinion, that the trap-rock formation was the original source of the masses of copper which have been observed in the country bordering on Lake Superior; and that at the present day, examinations for the ores of copper could not be made in that country with hopes of success, except in the trap-rock itself; which rock is not certainly known to exist upon any place upon Lake Superior, other than Keweena Point." The chief ore of copper that he had observed was the malaconite, although a small amount of native copper had been seen in place.

Dr. Douglas Houghton states, in his first Report on the Geology of Michigan,‖ that the red sandstone "in the Trap regions of Lake Superior, as in the vicinity of the Porcupine Mountains, ... is seen dipping irregularly at a high angle from the elevated district of country, and is there of a deep reddish-brown color." He evidently at that time regarded the sandstone as belonging to one formation, from the St. Mary's River to the Porcupine Mountains.

Dr. Houghton in his Fourth Annual Report on the Geology of Michigan,¶ divides the sandstones of Keweenaw Point as follows, going from below upwards: "conglomerate rock," "mixed conglomerate and sand rock," and "red sandstone and shales." He regards the first as a "trap-tuff," and as made up of "rounded masses of greenstone and amygdaloidal trap, of which the former make up by far the larger proportion, and scarcely a pebble of any other rock than trap, enters into its composition." The second is composed of the same materials as the first, and is conformable with it. The only difference is that part of it is made up of sand composed of finely comminuted greenstone. The last, or "the red sandstone and shales," he considers to differ widely from the preceding rocks, and to be made up of detritus of the granitic and metamorphic rocks, containing, however, some sand that appears to be comminuted trap. This red sandstone extended, according to Houghton, as far east as Grand Island, where it was unconformably overlaid by the "Gray Sand Rock" (e. g. the material of the Pictured Rocks), which rested upon the uplifted edges of the former. It will thus be seen that he had changed his views since his first report.

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* Am. Jour. Sci., 1824, (1,) VII. 43 - 49.

† Quart. Jour. Sci., 1824, XVIII. 1 - 34, 228 - 269; Am. Jour. Sci., 1824, (1,) VIII. 60 - 88.

‡ Trans. of the Lit. and Hist. Soc. of Quebec, 1829, I. 1 - 43.

§ Nov. 14, 1831. Discovery of the Source of the Mississippi, Henry R. Schoolcraft, New York, 1834, pp. 287 - 292.

‖ Lanman's Hist. of Mich., p. 353.

¶ Joint Documents, Mich., 1841, pp. 472 - 607.

All these rocks were said to be traversed by dikes injected parallel to the bedding, varying in width from fifty to four or five hundred feet. He considered that the sedimentary rocks were all deposited prior to the injection of the traps, which rocks he finds very abundant in the conglomerates, and comparatively rare in the red sandstones. These dikes pass from a compact greenstone on the southeast side to an amygdaloid on the northwest. He considers that they were "in an intense state of ignition while in contact with the sedimentary rocks, as is clearly shown by the very great changes that have taken place in the rocks last alluded to. In fact, I am disposed to refer the origin of much of the amygdaloid rock to the fusion of the lower portions of the sedimentary rocks referred to, for the reason, that as we pass south from this junction, the amygdaloid rocks wholly disappear, their place being supplied by greenstone; and again so intimately are they blended, that it is frequently impossible to determine where the amygdaloid ceases and the upper sedimentary rocks commence. Fragments of the sedimentary rocks, the characters of which can be clearly recognized, are not of rare occurrence, imbedded in the amygdaloid rock, a circumstance which although by no means conclusive, should not be overlooked in considering this subject. I would not wish to convey the idea that the amygdaloid rocks have their origin exclusively from the altered sedimentary rocks, but simply that the change in the structure of the trap, from greenstone to amygdaloid, may and no doubt does depend upon the proximity of the sedimentary rocks to the trap, while the latter was in a state of ignition." (*l. c.*, p. 490.) He states that the sandstones have evidently been deposited in shoal water, on account of the abundant ripple-marks occurring in them.

Three species of fucoids, tolerably well defined, were said to have been found in the red sandstone. The veins are considered to be of a date posterior to the uplifting of the beds, and cut across all three of the sedimentary rocks and the traps. They are taken as true veins, and their mineral contents are said to change in the same vein as the rock changes. The gangue is said to be principally quartz with occasional calcite, and the ore to be most abundant at or near the junction of the trap and conglomerate. He regards this district as being in its general characters and in its veins like Cornwall. Conglomerates were noticed with a cement of copper, but only in the immediate proximity to considerable veins. He conceived the veins "to be veins of sublimation, or in other words to be simply filled from below by the metal in a vaporous state, and that all the compounds had their origin from copper in a native form." * In 1843, he considered that the sandstone east of Keweenaw Bay was older than the Trenton, while the western sandstones and conglomerates were formed during the period in which the trap was upheaved, and were probably contemporaneous with the New Red Sandstone.†

It will be seen here that Dr. Houghton had entirely changed his views regarding the relations of the sandstone. In 1841, the sandstone of Keweenaw Point was said to be older than the St. Mary's sandstone; in 1843, to be younger.

Later, Dr. Houghton "said he could not speak definitely as to the contemporaneousness" of this sandstone with that of Connecticut and New Jersey, "but he was sure of the *similarity* of their structure." ‡ Prof. B. Silliman, Jr. at the same time stated that although he had found the copper and silver from this region "fused into perfect union at their two surfaces," they were not alloyed.§

Prof. John Locke, in an article in 1844,‖ entitled "Observations made in the Years 1838, '39, '40, '41, '42, and '43 to determine the Magnetical Dip and the Intensity of Magnetical Force, in several Parts of the

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* Am. Jour. Sci., 1841, (1,) XLI. 183-186; 1844, XLVII. 106. Trans. of the Assoc. of Am. Geol. and Nat., 1840-1842, pp. 35-38.

† Am. Jour. Sci., 1843, (1,) XLV. 160.

‡ Am. Jour. Sci., 1843, (1,) XLV. 332; 1844, XLVII. 107, 132.

§ Am. Jour. Sci., 1843, (1,) XLV. 332.

‖ Trans. Am. Phil. Soc., Phila., IX. 283-315, Apr. 19, 1844.

United States," presents the metamorphic theory of the origin of the rocks of Keweenaw Point as follows: "The rocks of Copper Harbour, and indeed of the whole Kewenon peninsula, are decidedly metamorphic, showing every degree of change produced by igneous agency, from unchanged sandstone to compact greenstone. The stratification is, mostly, more or less evident, presenting in the various superimposed layers, an inexplicable variety, some layers bearing evidence of semi-fusion and a correspondent degree of induration and endurance, while others seem scarcely to have been altered, still remaining soft and yielding readily to atmospheric agency, and especially to the assaults of the waves from the lake. Whether these differences have been produced by an unequal distribution of the heat, or by an original difference in the layers of the strata, some being of a nature more susceptible of change by heat, I was unable to determine. . . . . Copper Harbour itself seems to have been formed by the removal of a softer stratum of metamorphic sand rock, while Porter's Island is a part of the barrier formed by the outcropping of a harder layer." (*l. c.*, pp. 311, 312.)

In 1845,* Lieut. D. Ruggles published a communication in which he advanced the view that the trap was projected in dikes through the New Red Sandstone, and that the veins were formed and filled "by volcanic or igneous action, under the pressure of incumbent waters." If we can judge from his statements about the copper and his description of the filling of the veins in the "Lead Region" of Illinois, Wisconsin, and Iowa, he believed that these veins were filled by the projection of metallic copper, enveloped in a dense atmosphere of oxygen "from the fountain of igneous action, through fissures in the rock strata, resulting from concurrent disturbing causes." When the vein was "under the pressure of an immense mass of water," the oxygen entered into combination with the copper to form the black oxide of copper, but when only under atmospheric pressure the oxygen escaped by sublimation, leaving the copper to its own resources.

Dr. Chas. T. Jackson, writing in 1845,† regarded the sandstones as probably Permian or New Red, but attributed to Dr. Houghton the belief that the formation is Old Red, and also held that the trappean rocks were injected dikes. The veins were taken as veins of igneous injection, although doubt is expressed, and he says: "When these veins occur near the trap dykes, analcime and Prehnite also abound, and were formed, without doubt, through the igneous agency of the trap on the contents of the vein and the ingredients of the wall rock." We may infer from this, that he regarded the fissures to be of anterior formation to the traps. He states that "the trap rocks of Lake Superior pass through the red sandstone and conglomerate rocks, and are interfused with them, producing at or near their junction a very porous amygdaloid, which is always found at the lower side of the dyke where it is next to the sandstone." He also remarks that he finds the copper and silver "united together side by side by fusion without any alloying of the silver"; "the two metals are completely soldered together at their points of contact." This paper was also presented to the Association of American Geologists and Naturalists, at their sixth meeting, April 1845, published in their Proceedings (pp. 53-60), and discussed by Prof. C. U. Shepard (pp. 60, 61). He considered that the copper was derived from the sandstones by the action of the trap dikes upon them. The copper was originally in the primitive rocks, "whose lateral slopes were occupied with cupreous strata derived from the degradation of the surrounding primitive; and that whenever the trap had slid out beneath these deposits, or in other ways come in contact with them, they would, as elsewhere, bring to the surface rich masses of copper; but he was inclined to the opinion that they would not give rise to deep and permanent mines." He considered that the sandstones belonged to the New Red. In an earlier portion of the Proceedings (pp. 30, 31), Dr. Jackson remarked that "at the junction of the great dykes with the sandstones of Nova Scotia, Maine, and on Lake Superior, a more violent ebullition took place than that which accompanied the eruption of the trap ranges in Connecticut, for the sandstone and trap are blown into a perfect scoria at the former localities; amygdaloid resembling the most porous lavas, and immense quantities of trap tuff containing lumps of metallic copper, evince the powerful action of trap on the sandstones of Nova Scotia, and on Kewenaw Point, Lake Superior. . . . . On Kewenaw Point we have an intimate mixture of copper and trap rock in the amygdaloid, and I at first supposed if the amygdaloid resulted from the interfusion of sandstone and trap, that the copper might have been reduced from copper ores pre-existent in the sandstones; but the absence of such ores in the sandstone in contact with or near the trap appears to discountenance the idea, and I am more disposed, since I have explored that region, to coincide with the opinion of Dr. Houghton in the belief that the copper of that region is a part of the primary copper of the globe brought up by the viscid trap." At a meeting of the Boston Society of Natural History,* November 6, 1844, he remarked: "There can be no doubt, however, that the metals found in the Lake Superior amygdaloidal trap, have been fused at as high a temperature as was required to liquify the rocks in which they are found, for they bear evident marks of entire fusion, and are as vesicular as the common lavas of Vesuvius, Etna, and Peak of Teneriffe." * In one of the later papers† he states: "It is obvious, both from the crystalline forms and the mode of occurrence of this copper, that it was deposited from a state of igneous fluidity; and, from the circumstance that the walls of the vein are encrusted with Laumonite, it would appear that the spar vein itself is of igneous origin. Many other instances of a similar kind indicate that the calcareous spar veins, which traverse the conglomerate and sandstone rocks, are true veins of igneous origin."

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* Am. Jour. Sci., (1,) XLIX. 62-72.

† Ibid., pp. 81-93.

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* Proceedings, I. 203.

Mr. Bela Hubbard ‡ regarded the sandstones on both sides of Keweenaw Point as Potsdam in age, and held that the traps were eruptive in it. He regarded, however, the conglomerate and the "mixed conglomerate and sand rock" lying to the northwest of the Point as of later origin than the trap and composed of its *débris.* Concerning the "mixed conglomerate and sandrock" he states: "As the finer strata of this rock have been mistaken by some for the red sandrock, hereafter described, it is important to observe that a very marked difference exists between the two rocks; for, while the latter is made up of materials derived from the several rock formations of the country, and into which quartzose grains enter most largely, the former is wholly derived from the trap rocks." The "red sandrock" is said to be in nearly horizontal strata, but having on the coast a slight dip inland, which becomes "more apparent as it approaches the basin of Portage Lake. In its approach to the trap, however, it is found more or less tilted from its original horizontal position, and is also very much altered by its contact with that igneous rock. The evidences both of the deposition of this extensive formation, in calm and shallow waters, and of the subsequent changes induced in it by the trap rocks, when in a fused or heated state, are very apparent."

Prof. H. D. Rogers § stated that "at the Eagle River mine, and elsewhere, the metalliferous rock is not, as sometimes supposed, a real trap rock, but a mixture of trappean matter, and that of the red sandstone formation, more or less baked and modified by intense igneous action. These semi-fused materials, in crystallizing, have very frequently resulted in the following curious arrangement: the crystalline metallic copper occupies the centre of globular and variously formed concretions; calcareous spar usually, but not always, invests the copper; and very generally the exterior of the kernel is pure crystalline chlorite. . . . . These nodular lumps are dispersed through a base which exhibits a sort of pasty mixture of softened red shale and true trappean matter; and many of them are so surrounded as to indicate them to be true segregations from this semi-igneous, semi-aqueous compound." He regarded the sandstone as equivalent to the New Red sandstone of the Atlantic States, and making the same formation throughout the peninsula of Upper Michigan. In a report on the sale of mineral lands by Mr. Relfe we find the following statement: "In the conglomerate rocks which overlay the trap, are to be found all the varieties of copper ore of the richest qualities, offering to the smelter a greater yield than has ever been obtained from the copper ores of England or other countries that have contributed so largely of this important article." *

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* See also Proceedings of same Society, II. 110-114, Mar. 4, 1846. Am. Jour. Sci., (2,) II. 118, 119.

† Proc. Bost. Soc. Nat. Hist., 1846, II. 112.

‡ Mineral Region of Lake Superior, by J. Houghton, Jr. and T. W. Bristol. See also Senate Documents, 1849-50, 31st Cong., 1st Sess., III. 802-842, and 1845-46, 29th Cong., 1st Sess., VII., No. 357, pp. 2-29.

§ Proc. Bost. Soc. Nat. Hist., April 1, 1846, II. 124, 125.

Sir Wm. Logan in the Report of Progress† regarded the copper-bearing traps of Lake Superior as of a higher antiquity than the Potsdam Sandstone, and attributes the same view to Dr. Houghton in 1841. Logan's statement seems to be erroneous regarding Dr. Houghton's views in this respect. He considered the traps older than rocks which Logan regards as Potsdam sandstone, but of whose age he expressed no opinion in his Report for 1841, to which Logan refers. In 1843, as we have seen before, Dr. Houghton not only took the copper-bearing rocks to be of the age of the New Red sandstone, but also considered Logan's Potsdam sandstone as belonging to some formation older than the Trenton. In this way he had reversed his view of the order of succession in 1843, which Logan attributed to him as late as 1847. (*l. c.*, p. 34.)‡

Mr. Bela Hubbard in his report for 1846 § states concerning the trap of the Porcupine ranges that, "while we desire to avoid any theoretical conclusions as to the mode of their formation, we cannot but observe that the character of the entire trap formation is rather that of a succession of overflows, than of simultaneous uplift in mass; in other words, it may be considered as made up of *beds* of the different kinds superimposed upon each other." He also regards the "*epidote veins*" as in the main contemporaneous beds whose mineral contents were deposited with the bed.

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* Reports of Committees, 29th Cong., 1st Sess., Vol. III., Doc. 591, pp. 2, 3, 1845 – 46.

† Geol. of Canada, 1846 – 47.

‡ 1849 and 1851, Reports of Progress. North Shore of Lake Huron, p. 20; Brit. Assoc., pp. 59 – 62, 1851.

§ Senate Documents, 1849 – 50, III. 371 – 935, p. 887.

Dr. D. D. Owen, in his Report of a Geological Reconnoissance of the Chippewa Land District of Wisconsin, etc.,* of the date of April 23d, 1848, regarded the sandstone of Lake Superior as younger than the Carboniferous age, basing his conclusions, as Dr. C. T. Jackson had done, on lithological and mineralogical characters only. (*l. c.*, pp. 57, 58.) In his final report (Oct. 30th, 1851, pp. 187–193), this view was abandoned, and the sandstone regarded as Potsdam.

Dr. C. T. Jackson † remarked in 1848 that the sandstone agreed in its characters with those of the oldest of the sandstone formations. On Jan. 2d, 1850, (*l. c.*, p. 228,) he stated that he wished to correct the record, as the preceding view of the age of the sandstone should be accredited to his assistants, Messrs. Foster and Hill, and not to himself.

Mr. James T. Hodge ‡ seems to regard the veins as filled by igneous injection and sublimation. The silver was injected after the copper had cooled and occupied the spaces left by the contraction of the latter on cooling.

Dr. Charles T. Jackson in his report (pp. 392, 398, 399, 471 – 473),§ transmitted November 10th, 1849, stated that the amygdaloid was formed by "the interfusion of the red sandstone and trap," and the trap rocks are distinctly stated to have burst through and between the strata of the pre-existing sandstone. He calls attention to the mooted question whether the trap rocks originated from the molten interior of the earth, or were derived from the re-fusion of the lower stratified rocks (p. 397). The sandstone and conglomerate are said to have been derived from granite, gneiss, or mica slate and porphyry. The porphyry is thought to have resulted "from the semifusion of the finer materials of the sandstone. It is evident at once, from inspection of the pebbles of the conglomerate, that they have been ground into their present shape by long attrition under water, or upon some ancient shore. . . . . They originated from some nether rock, or were transported to their present location by drift agencies." Dr. Jackson will then stand next in order of time to Rev. J. G. Cumming in suggesting the idea of drift agencies in the earlier geological periods.* May we suggest that these conglomerates are the lateral moraines of the ancient glaciers which scooped out the basin of Lake Superior, and that the coldness of the waters at the time of the melting of these glaciers prevented the existence of life then. In this way we account for the Lake basin, the conglomerates, and the absence of fossils, three difficult problems. As we now know the geological structure of the country to be different from that supposed by Dr. Jackson, there exists an excellent field here for speculation concerning the number of glacial periods during the time of the deposition of the rocks of Keweenaw Point, the connection of glaciers with volcanic action and the eccentricity of the earth's orbit. It is very probable that the ice by its weight carried the sedimentary strata downwards, the same pressure aiding in their igneo-aqueous fusion (solution), while the thickness of the ice mass would cause the geothermal *couches* to rise, thus enabling us to account for the lavas. This leads us to the consideration of the effect that glaciers may have in forming lake bottoms by their pressure bending the underlying strata, the displaced material being erupted along the sides of the depression. We can thus account for the proximity of volcanoes to large bodies of water, and explain the cause of the highest mountains being adjacent to the deepest oceans, their successive elevations corresponding to the different glacial epochs. If the Atlantic is to be filled with a solid mass of ice to account for the loess of the Rhine, and the Southern oceans to be filled in like manner to explain the geographical distribution of the New Zealand fauna, why cannot Lake Superior also be filled, when it will cost so little and explain so much?

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* Senate Documents, 1st Sess., 30th Cong., 1847 – 48, VII., Doc. 57, 134 pp.

† Proc. Bost. Soc. Nat. Hist., III. 76, 77, Nov. 1st, 1848.

‡ Proc. Am. Assoc. Adv. Sci., Aug. 20th, 1849, II. 301 – 308.

§ Senate Documents, 1849 – 50, III. 371 – 935. See also Proc. Am. Ass. Adv. Sci., II., 1849, Aug. 20, pp. 283 – 301; Bull. Geol. Soc. France, (2,) Vol. VII., 1849 – 50, pp. 667 – 673, and Am. Jour. Sci., (2,) Vol. X., 1850, pp. 65 – 77.

Dr. Jackson further considers the sandstone as belonging to the New Red, stating that it has been absolutely proved not to be Potsdam. He seems to have receded from his former views regarding the filling of the fissures by vein material and not to have adopted any others in their places. He would, however, consider that the copper and silver "were produced by igneous agency. . . . . The copper and silver occur on

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* History of the Isle of Man, 1848, p. 89. See also F. B. Hough, Proc. Am. Assoc. Adv. Sci., 1851, VI. 262–264; and the Quart. Jour. Geol. Soc., VI. 96, 97, 1850, R. Godwin Austin; XI. 185–205, 1855, A. C. Ramsay.

Lake Superior mineral lands in the trap rocks only, and the valuable veins are limited to a narrow belt of the amygdaloidal variety of that rock." (*l. c.*, p. 471.) Mr. J. W. Foster (May 26, 1849, *l. c.*, pp. 773–785) regarded the sandstone "as resting at the base of all the fossiliferous rocks."

In Foster and Whitney's Report to the Land-Office (*l. c.*, p. 607), it is stated that "what is generally known as the trap range, consists of a belt of igneous rocks, composed for the most part of hornblende and felspar, which in places have broken through the sandstones, tilting them up at high angles; but oftener are found in alternating beds, having the same dip as the detrital rocks. The associated sandstone and conglomerate belong to the silurian system, and rest at the base of all fossiliferous rocks." Concerning the copper it is stated: "Some of these accumulations of copper are mere beds, the result of segregation, while others are contained in fissures, formed subsequent to the containing rock, and associated with a veinstone entirely dissimilar." (*l. c.*, p. 608.)

The final report of Messrs. Foster and Whitney on the Copper Lands was presented April 15, 1850.* Regarding the trap range of Keweenaw Point, it is stated that "this range does not appear to have been the result of one, but of successive overflows; for we not only find the igneous materials arranged in parallel bands, and exhibiting great diversity in external characters, but we also find numerous intercalations of conglomerate of inconsiderable thickness, but extending for miles in a linear direction — these mixed products being associated in regular beds, having a common bearing and inclination, so that the inexperienced observer is inclined to refer the whole to a common origin. This deception is still further increased by observing lines of pseudo stratification in the trap conforming to those of the associated sedimentary rocks." (*l. c.*, p. 61.)

The southern trap range of the Point is said to consist of "a vast crystalline mass, forming an anticlinal axis, flanked on the north by the bedded trap and conglomerate, and on the south by conglomerate and sandstone." (*l. c.*, p. 64.) Towards Portage Lake none of this trap was protruded, but it was thought that the same fissure extended along this line from the "head of Keweenaw Point to the western limits of the district." (*l. c.*, p. 68.) Regarding the relations of the sandstone to the trap on Keweenaw Point and Isle Royale, they say: "As a general observation, the *upper* portions of these sandstone belts are much more changed by heat than the lower." (*l. c.*, p. 63.) "The *upper* portions of the sheets of trap are highly vesicular, resembling pumice.

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* Executive Documents, 1st Sess., 31st Cong., 1849–50, IX., Doc. 69, 224 pp.

Fragments of amygdaloid, sometimes rounded, at others angular, are found enclosed in the pumice-like trap, as though they had become detached and afterwards reunited to the mass, while in a molten state. Numerous short and irregular fissures, extending to no great depth, are observed on the upper surface of the trap, in which sandstone has been deposited. . . . . Between the *sandstone above* and the *trap below*, it is extremely difficult to determine where the one begins, and the other ends. Fragments of amygdaloid, angular or partly rounded, are included in the sandstone — more numerous near the base than at the top of the deposits. Where the sandstone is imposed *on* the trap, there is little evidence of its having been metamorphosed; but, on the other hand, where the trap rests *on* the sandstone, the line of junction is clear and well defined. The trap is less vesicular; and the upper portion of the sandstone belt, for the distance of three or four feet, is converted into a ribbon jasper, having a compact texture. These phenomena have been observed at numerous places both on Isle Royale and Keweenaw Point. The beds of sandstone are not shattered, nor does the igneous rock penetrate in the form of dikes or ramifying veins. All the phenomena indicate that the igneous rocks were not protruded in the form of dikes between the strata, but that they flowed like lava sheets over the pre-existing surface; and that the sand was deposited in the fissures and depressions of the igneous belt, in some cases while the mass was in an incandescent state." (*l. c.*, p. 87.) The conglomerate is regarded as a volcanic tuff, and the sandstone as Potsdam in age. The conglomerate of Keweenaw Point and Isle Royale "consists of rounded pebbles of trap, almost invariably of the variety known as amygdaloid, derived probably from the contemporaneous lavas, and rounded fragments of a jaspery rock which may have been a metamorphosed sandstone, the whole cemented by a dark-red iron sand. This cement may be regarded as a mixture of volcanic ash and arenaceous particles, the latter having been derived from the sandstone then in the progress of accumulation. . . . . The trappean pebbles often attain a magnitude of eighteen inches in diameter. Their surfaces do not present that smooth, polished appearance which results from the attrition of water. . . . . The conglomerate appears to have been formed too rapidly to suppose that the masses were detached and rounded by the action of waves and currents, and deposited with silt and sand on the floor of the ancient ocean; for, while the contemporaneous sandstone remote from the line of volcanic foci does not exceed three hundred or four hundred feet in thickness, the united thickness of the conglomerate bands in the vicinity of the trappean range on Keweenaw Point exceeds five thousand feet. As we recede for a few miles from the line of the volcanic fissure, these amygdaloid pebbles disappear, and are replaced by arenaceous and argillaceous particles." (*l. c.*, pp. 99, 100.) "Although the conglomerate attains a thickness of five thousand feet, yet it by no means follows that the ancient sea in which it was deposited extended to that depth. Ripple-marks and clay-cracks have been observed in the upper portions of this group ; the one indicates comparatively shoal water, and the other the ebbing and flowing of a tide, or a change in the level of the water. The inference, therefore, is, that during the deposition of the conglomerate, the bed of the sea was subject to repeated elevations and depressions, caused by volcanic action, and that its water obeyed the same tidal laws which govern the existing oceans. These conglomerates, then, may be regarded as local deposites formed along the courses of the volcanic fissures by the joint agency of fire and water. When the former causes operated with intensity, the materials consisted of spherical masses of lava and scoriæ. When they acted feebly, or were quiescent, the materials became argillaceous or arenaceous." (*l. c.*, p. 109.) "We have seen that, during the deposition of the sandstone, numerous sheets of trap were ejected, and flowed like lava-streams ; and that the igneous and aqueous products were so intermingled as to present the appearance of having been derived from a common origin ; and that subsequently the unbedded trap broke through these parallel fissures, lifting up the sandstones, conglomerates, and bedded traps, and causing the whole mass to dip at high angles." (*l. c.*, p. 110.) The sandstone on both sides of Keweenaw Point, and the trap, were regarded as making one geological formation.

While the sandstone is stated to dip near the southern range of trap above Bête Grise Bay 78° southeast (*l. c.*, p. 112), farther up Keweenaw Bay the prevailing dip was said to be about 5° to the northwest (*l. c.*, p. 116). The veins were regarded as probably filled by materials "once held in aqueous solution and precipitated by electro-chemical agency," while the theories of sublimation and injection were controverted (*l. c.*, pp. 174, 175). The veins were fully described so far as then known, as well as the order of deposition of the minerals and associated copper, etc., etc.*

Prof. Louis Agassiz, in discussing the "Geological Relations of the various Copper Deposits of Lake Superior,"* wrote concerning the copper ores: "They seem to me clearly to indicate that the native copper is all plutonic; that its larger masses were thrown up in a melted state; and that from the main fissure through which they have found their way, they spread in smaller injections to considerable distances; but upon the larger masses in the central focus, the surrounding rocks could have little influence. New chemical combinations could hardly be formed between so compact masses, presenting, in comparison with their bulk, a small surface for contact with other mineral substances capable of being chemically combined with the copper. But where, at a distance, the mass was diffused in smaller proportions into innumerable minute fissures, and thus presented a comparatively large surface of contact with the surrounding rocks, there the most diversified combinations could be formed, and thus the various ores appear in this characteristic distribution. The relations which these ores bear to the rocks in which they are contained, sustain fully this view, and even the circumstance that the black oxide is found in the vicinity of the main masses, when the sulphurets and carbonates occur at greater distances from them, would show that this ore is the result of the oxidation of some portion of the large metallic masses exposed more directly to the influence of oxygen in the process of cooling. Indeed, the phenomena respecting the distribution of the copper about Lake Superior, in all their natural relations, answer so fully to this view, that the whole process might easily be reproduced artificially on a small scale; and it appears strange to me that so many doubts can still be expressed respecting the origin of the copper about Lake Superior, and that this great feature of the distribution of its various ores should have been so totally overlooked."

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* See also Bull. Geol. Soc. France, (2,) VII. 1850-51, pp. 89-100 ; Proc. Am. Assoc. Adv. Sci., 1851, V. 22-38, 136-151 ; and Am. Jour. Sci., (2,) 1851, XII. 222-239.

Prof. J. D. Dana remarked: "The copper occurs in trap or sandstone, near the junction of these two rocks, and has probably been produced through the reduction of copper ores by the heat of the trap when first thrown up." † This view is retained in his later editions of the same work.‡

Dr. C. T. Jackson later advocated his former view that the sandstone of Keweenaw Point was of the same age as the New Red sandstone of Europe, but in addition he claimed that this sandstone (New Red) was a member of the Upper Silurian.* Later, Mr. Jules Marcou advocated the view that this sandstone was of the age of the New Red, and opposed the ideas of Messrs. Foster and Whitney.† At the meeting of the British Association for the Advancement of Science, July, 1851, Sir W. E. Logan ‡ advanced the idea that the sandstone and its associated traps were older than the Potsdam, and of Cambrian age. This view was based on the idea that the azoic rocks north of Lake Huron were the same as the traps of Keweenaw Point.§ Dr. D. D. Owen, as mentioned before, in his "Geological Survey of Wisconsin, Iowa, and Minnesota" (pp. 187–196) regarded the sandstone as of the same age as the Potsdam of Wisconsin, but Col. Chas. Whittlesey (Ibid., pp. 459 – 461) was inclined to think it was older. Dr. J. J. Bigsby ‖ believed the sandstone to be Cambrian (or Silurian). Later, Dr. C. T. Jackson advocated the igneous origin of the calcite veins in this region.¶ Mr. Jules Marcou, in his "Geological Map of the United States, with Text," held that the sandstone was of the age of the New Red, and apparently regards the trap as having been injected in the form of dikes. The copper veins were also thought to be dikes, with the copper of like igneous origin. This work gave rise to a long controversy, in which the age of the sandstone was quite thoroughly discussed; but in only a few cases shall we refer to the various articles elicited by it. Those interested in the literature of the Marcou-Anon.-Agassiz-Barrande-Blake-Dana-Hall-Hunt-Logan-Murchison-Whitney controversy will find the principal articles, that have any bearing on the geology of Lake Superior, given under the names of the different authors in the list of articles at the end of this paper.

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* Lake Superior: its Physical Character, Vegetation, and Animals, (Boston, March, 1850,) pp. 427, 428.

† System of Mineralogy, 3d ed., May, 1850, p. 508.

‡ 4th ed., 1854, Part II. p. 17; 5th ed., 1868, p. 15.

The same views regarding this district that were given in Messrs. Foster and Whitney's Report on the Copper Lands were again presented in brief in Professor Whitney's "Metallic Wealth of the United States." ** Dec. 5th, 1855, Dr. Jackson explained the deposition of the copper in the veins "as the result of the chemical action of protoxide of iron in the trap-rock, which decomposed the vapor of chloride of copper, as it rushed from the interior of the earth through the crevices; if, as is probable, these wonderful native copper lodes, are the products of sublimation and of galvanic segregation of the metal from vapor." He defined the ash bed as a "comparatively soft scoria, or rotten amygdaloid, formed by the mixture of molten trap-rock and fine sandstone, which have been, as it were, melted together into a very spongy kind of scoria, the aqueous vapor having rendered it remarkably vesicular." * He regarded the trap as having been "poured out, at different times, through a fissure, and spread over the materials of the sandstone and conglomerate at the bottom of the sea, thus producing alternating beds of these rocks," while in July, 1856, he seems to have regarded the trap as forming dikes in the sandstone, and combining with its ingredients to form the zeolites.† Prof. L. E. Rivot ‡ regarded the traps as interstratified sedimentary beds metamorphosed *in situ.* The sandstone formed the upper portion of, and was conformable with, the copper series ; all to the Sault St. Marie making one geological horizon, including the granites and iron-bearing rocks. All were taken to be of the Potsdam age. The veins were considered to have been produced by elevation and fracture since the deposition of the entire series, and the copper deposited in the wet way.

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* Proc. Bost. Soc. Nat. Hist., Oct. 2 and 16, 1850, III. 335 – 339. See also Bull. Soc. Geol. France, (2,) 1849 – 50, VII. 209, Elie de Beaumont.

† Bull. Soc. Geol. France, 1850 – 51, (2,) VIII. 101 – 105.

‡ Trans. of the Sections, pp. 59 – 62.

§ See Am. Jour. Sci., (2,) 1857, XXIII. 305 – 314.

‖ Edinburgh New Phil. Jour., 1852, LIII. 55 – 62.

¶ Proc. Bost. Soc. Nat. Hist., 1853, IV. 308, 309.

** Philadelphia, 1854, pp. 247 – 305. Am. Jour. Sci., (2,) 1857, XXIII. 305 – 314.

In 1856 a "Report on the Exploration of Lakes Superior and Huron," was presented to the Legislative Assembly of Canada by Count de Rottermund. It probably proved satisfactory, as we do not learn that the Assembly asked for any further information from him. In the narrative portion we are informed : "I procured a boat with four hands and proceeded to Portlock Harbour. . . . I met Mr. Salter with whom I returned to the Bruce Mines. There we parted our provisions and separated." (*l. c.*, p. 1.)

He attempts a classification of the formations visited, and states that "this classification demands great attention, and very minute discrimination, to avoid the solecism of giving names according to individual fancy, not used in the scientific world. Such are the names applied to formations in Canada of Huronian, Sillery, Laurentine, Richelieu, peculiar to the localities which they indicate, substituted for Jurassic, Carboniferous, Cambrian, Devonian, etc., which are so well classified, defined, and admitted throughout the scientific world." (*l. c.*, pp. 4, 5.)

His theory of the origin of the copper is too lengthy for insertion ; it must be read to be appreciated. The result is summed up as follows : "On Lake Superior the copper, in its native state is due to the deposit of certain species of organic matters which have a tendency to increase the electro-chemical action, and which decomposed the sulphurets, oxides, etc., which the abundant deposit of matter containing traces of talc serpentine and chlorites, has brought together or concentrated in a certain limited space. For nearly all the rocks contain in the crystalline cleavage, and also in the veins these matters which appear sometimes to be a sort of cementation, if, indeed, it be not the state of combination of detritus, of disintegration of primitive rocks which have arrived at the state of sandstone and greywacke." (*l. c.*, p. 13.)

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* Proc. Bost. Soc. Nat. Hist., 1855, V. 279-281; 1859, VII. 31.

† Ibid., VI. 23, 24.

‡ Annales des Mines, (5,) 1855, VII. 173-328 ; 1856, X. 364-474.

This report is not without interest to the archæologist as the following proves: "I have in my possession locks of hair enveloped in copper, which the natives carried about them as marks of their bravery. Whenever they killed their enemy they used to cut off a lock of hair and carry it about them as a species of decoration. In places where there is no copper they cut off with the hair a small portion of the skin, which is called the scalp." (*l. c.*, p. 16.)

The student of Indian customs can, of course, now greatly aid the miner in his prospecting, if he will carefully map the districts inhabited by the non-scalping, copper-bearing Indians, for hereafter it will be of no avail to look for copper outside of their habitat.

Alb. Müller, in 1856, published a paper relating to the copper of this district.* His facts were taken mostly from the report of Foster and Whitney, and it is unnecessary to repeat them here. He regarded the copper as being deposited in the wet way, by the aid of galvanism, and reduced by organic matter and the oxide of iron. The copper, it is supposed, might have existed in the trap and its minerals, in minute amounts, until brought to the points where it is now found. The student interested in the origin and deposition of the copper will do well to read the writings of Foster and Whitney, Whitney, Müller, Bauerman, and, lastly, those of Marvine and Pumpelly.

Principal J. W. Dawson remarks † concerning the deposition of the native copper: "The whole of the appearances indicate that the deposition of copper belongs to the period of aqueous infiltration, by which the veins and vesicles were filled after the consolidation of the trap; and the copper, like the calc spar and zeolites, occurs both in true veins and in the cavities of beds of vesicular trap and tufa. Its deposition must, therefore, be explained, not by igneous causes, but by electro-chemical agencies, decomposing some soluble salt, most probably the sulphate, of copper. Such changes may have been aided by the remaining heat of portions of the volcanic masses, by the presence in them of large quantities of iron in low states of oxidation, and by the further oxidation of that metal evidenced in the red jasper and red laumonite of the veins, and the red conglomerate and sandstone associated with the trap. . . . . The main fact in relation to the origin of the metallic copper, is that it is a product, not of the fusion of the trap, but of subsequent processes, by which the fissures of that rock were filled by materials regarded as of aqueous origin." (*l. c.*, pp. 8, 9.)

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* Verhandlungen der Naturforschenden Gesellschaft in Basel, 1854-57, pp. 411-438.

† Feb. 10, 1857. Canadian Nat. and Geol., II. 1-12.

In 1857, Dr. J. D. Dana* stated that the veins occur "mostly in the trap rock which intersects a red sandstone, probably identical in age with the red sandstone of Connecticut and New Jersey." April 6, 1859, Dr. Jackson inclined to the view that the zeolites had been formed "under the heat of the trap rocks, and the influence of heated saline waters." † Prof. James Hall, in his Palæontology of New York,‡ says: "In the region of Lake Superior, the sandstone, of the age of the Potsdam sandstone, has accumulated to a degree unparalleled in any other known locality of that rock. In this region there are not only massive accumulations of trappean matter, but outflows which have spread over the strata during their deposition; the beds of stratified amygdaloid trap alternating with the shale and sandstone, often equalling or exceeding the sedimentary matter."

In 1861, Dr. T. Sterry Hunt, following Logan, referred the sandstone with its accompanying trap to the Quebec group.§ Prior to this,‖ Prof. W. B. Rogers supported the view that this sandstone was of Potsdam age, and was opposed in this by Dr. Jackson.

In his Manual of Geology,¶ Dr. Dana refers the sandstone partly to the Potsdam and partly to the Calciferous epoch. In the edition of 1874, it is regarded as Calciferous. Dr. Dana further remarks concerning the copper, that "the native copper of the Lake Superior region is intimately connected in origin with the history of the trap and sandstone. The copper occurs in irregular veins in both of these rocks near their junction; and whenever the trap was thrown out as a melted rock, the copper probably came up, having apparently been derived from copper-ores in some inferior Azoic rocks through which the liquid trap passed on its way upward. The extent to which the rock and its cavities are penetrated and filled with copper shows that the metal must have been introduced by some process before the rock had cooled." *

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* Man. of Min., 2d ed., p. 305.

† Proc. Bost. Soc. Nat. Hist., 1859, VII. 45-47.

‡ Vol. III. p. 79, 1859.

§ Am. Jour. Sci., (2,) 1861, XXXI. 216-220, 392-414; 1862, XXXIII. 320-327. Canadian Nat. and Geol., 1861, VI. 81-105, 199-207.

‖ Proc. Bost. Soc. Nat. Hist., Nov. 17, 1860, VII. 394-399.

¶ 1862, pp. 172-174.

In the Geology of Canada, 1863, the copper-bearing rocks are considered, by Sir W. E. Logan, to be of the Calciferous and Potsdam formations, but overlaid by the Eastern sandstone, which was regarded as Chazy (pp. 67 – 86). Dr. Hunt seems to regard the "ash-bed" of Copper Falls as a conglomerate, and further says, regarding the Portage Lake deposits: "Certain of the sedimentary beds thus impregnated with native copper, are often designated as volcanic tufa or volcanic ash. From whatever source derived, however, the amygdaloidal rocks were deposited from water; and the copper which is disseminated in them, as well as in the sandstones and conglomerates, was separated by chemical processes from aqueous solutions, either contemporaneously or by subsequent infiltration. There appears to be no doubt that the traps which are interstratified with the sandstones and amygdaloids of this region, are eruptive rocks; and the sedimentary material of which the amygdaloids and tufas are composed may perhaps have been, to a greater or less extent, erupted in the form of volcanic mud, as many geologists suppose. This origin of the sediment has probably, however, no connection with the source of the copper." (pp. 698, 699.) He takes the entire formation, as before, to belong to the Quebec group.

In 1866, Mr. Thomas Macfarlane regarded the rocks at Portage Lake as melaphyrs.† In 1868 (*l. c.*, p. 256), he appears to regard the sandstone as being of the Permian age, basing his conclusions upon the lithological characters of the melaphyrs, while those who had regarded it as Triassic have based their views upon the lithological characters of the sandstone. One method is about as valuable as the other, a flow of basalt lava or a deposit of sand not being apt to be dated *per se.* Colonel Whittlesey, in describing the continuation of this formation in Wisconsin, makes the copper-bearing trap a formation below, but conformable with the Potsdam sandstone.‡ Mr. H. Bauerman § suggests, besides the hypothesis of Müller, the following to account for the occurrence of the copper: "The presence of copper in the sandstones suggests another origin — namely, that it may have originally been deposited with the quartz-ore sediment as a finely divided sulphide from sea-water under the influence of organic matter, and by subsequent oxidation and solution have been removed and collected in the rocks below. . . . . The size of the accumulated masses of metal appears to be mainly dependent upon the size of the cavities in which they are deposited, whether in the amygdaloids or in the main fissures; and their absence in the compact traps is probably only due to the non-occurrence of such cavities. In almost all cases the introduction of the metal has been preceded by the deposit of minerals produced from the decomposition of the rock, such as quartz, calcite, chlorite, and zeolite; and in the larger cavities it is often followed by transparent crystals of calcite, which are formed over branching masses of copper, or even show signs of simultaneous deposition, being filled with fire-spangles of metal arranged parallel to the diagonal striations or lines of growth on the rhombohedra. Similar alternations in the formation of zeolites, more particularly analcime, have been described by Whitney." He is inclined to regard the deposition of the copper in the amygdaloids as having taken place prior to the filling of the veins, the former serving as feeders to the latter. (*l. c.*, pp. 460, 461.)

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* Edition of 1862, p. 195; see also edition of 1874, p. 186.

† Geology of Canada, 1866, pp. 149 – 164. Canadian Nat. and Geol., (2,) III. 1 – 18.

‡ Proc. Am. Assoc. Adv. Sci., 1867, XVI. 97 – 107.

§ Quart. Jour. Geol. Soc., 1866, XII. 448 – 463.

In a paper read before the Boston Society of Natural History, June 5, 1867,* Mr. Alexander Agassiz remarks: "Foster and Whitney, in their Report of the Lake Superior mineral district, represent the sandstone on the south side of the trap range of Keweenaw Point as dipping south and resting conformably upon the beds of trap of the north side of the anticlinal axis of Keweenaw Point. This anticlinal axis formed by the Bohemian Mountain, as asserted by Foster and Whitney, is not found further south as far as I have had occasion to examine. In two of the ravines cut through the sandstone by creeks flowing in an easterly direction from the crest of the range towards Torch River, near the head of Torch Lake, we find good exposures of the sandstone resting unconformably upon the trap which has still the same northern dip as further west, of about 42°. The sandstone within a distance of one hundred feet from the trap, dipping north 42°, lies horizontally, or rather has at the outside an inclination of 1½° or 2° south." At the falls of the Douglass Houghton Creek, he says: "The creek winds its way through a deep ravine cut out of the sandstone, and at the junction of the sandstone and trap, falls a depth of one hundred and seventy-two feet. The chloritic bed is well developed on the south side of the creek, while the north side is more greenstone, and all along the whole length of the ravine up to the falls, a distance of one and one-half miles, the horizontal beds of sandstone are readily traced, dipping slightly north near the falls, and being horizontal at the opening of the ravine into Torch River valley, plainly showing that they rest unconformably upon the trap range. On examining this sandstone more carefully, we find that the strata are made up of alternating layers of sandstone of reddish or yellowish grain, and of beds of loose sandstone containing boulders; some of the beds of boulders resembling what is common on sea-shores as a mixture of mud and shingle. On breaking open several of the small boulders taken *in situ* from the beds we find that they consist mostly of reddish trap, but frequently we come across perfectly well water-worn boulders of grayish trap containing amygdales, identical with the trap of the copper range a short distance west from these beds of sandstone, plainly showing that the sandstone was deposited upon the shores of the ridge of trap forming Keweenaw Point, and has not been uplifted by it as is stated by Foster and Whitney. The case is totally different with the sandstone north of the range that lies conformably upon the trap, but the sandstone of the southern side of the mineral range in the vicinity of Torch Lake is plainly of a different age, lying, as it does, unconformably upon the former."

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* Proceedings, XI. 244-247.

In some respects it would seem that Mr. Agassiz, in common with many geologists, had misunderstood the views of Messrs. Foster and Whitney. Their idea was that the traps and sandstone comprised the same formation. The present visible portion of the eastern sandstone had, like the western one, been laid down since the trappean overflows.

After the deposition of the entire series a fissure was formed running along the Point from its head to the western limits of the district. This was attended in the northeastern portion by the protrusion of trap forming the Bohemian Mountains, but towards Portage Lake the fissuring was accompanied only by the elevation of the sandstone and trap west of the line, while that east of it remained nearly horizontal. As no stratified rock can rest conformably on the intrusive mass which uplifts it, so the sandstone was not supposed to rest conformably on the Bohemian trap. They also did not in their final report regard the sandstone along this fissure at the Douglass Houghton fall as dipping southerly, although Mr. Foster had stated so in a previous report to Dr. Jackson.* That Messrs. Foster and Whitney had this idea was probably inferred from the fact that the printer placed the eastern side of their section on the left hand, as was also done with that of the Copper Falls mine.* Their idea then would be perfectly consonant with the presence of trappean pebbles in the eastern sandstone as well as in the western, only they would have been deposited prior to the faulting, instead of after it, as Mr. Agassiz's view would demand.

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* Senate Doc., 1849-50, III. 783.

Mr. Robert Bell† regards the Upper Copper-bearing rocks as being of Permian or Triassic age. This conclusion was based on the lithological characters, and was objected to by Sir Wm. Logan in the same report (pp. 472–475).

Prof. R. Pumpelly in 1871 published a paper on "The Paragenesis and Derivation of Copper and its Associates on Lake Superior,"‡ a subject which had been treated of before by Messrs. Whitney, Müller, and Bauerman. He remarks: "The eastern limit of the 'range' is formed by a strongly marked and generally vertical plane of demarkation between the highly inclined cupriferous series of rocks and the sandstones which slope gently to the S. E. This sudden break is considered, with probably the best of reasons, by Foster and Whitney, and afterwards by Rivot, to be a longitudinal fracture accompanied by a dislocation of at least several thousand feet. Foster and Whitney looked upon the sandstone as the equivalent of the Potsdam, while the Geologists of the Canadian Survey refer it to the Chazy, and both authorities agree in considering it to be younger than the cupriferous rock, and of the same age as the sandstone beds, which are conformably superimposed over the trappean series on the west side of Keweenaw Point."

Prof. Pumpelly, it would seem, believed that the copper was deposited in the places in which it is now found by being precipitated from solution through the agency of protoxide of iron. He further considered that the copper was derived by concentration from the sedimentary members of the series. He remarks that "it is still an open question whether the trap which formed the parent rock of the melaphyr was an eruptive or a purely metamorphic rock. If it was eruptive, it was spread over the bottom of the sea in beds of great regularity, and with intervals which were occupied by the deposition of the beds of conglomerate and sandstones." (*l. c.*, p. 352.) The general tenor of this and his other papers shows that at this time, and for some years afterward, he leaned strongly towards the theory of the sedimentary origin of the entire trappean series. At this time he also regarded the traps, with all the sandstone as far east as at least the Pictured Rocks, as belonging to the Quebec group. It will be seen that he afterwards abandoned these views.

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* Copper Lands, pp. 63, 68.

† Geology of Canada, 1866–69, p. 321.

‡ Am. Jour. Sci., (3,) II. 188–198, 243–258, 347–355.

Later, Prof. Pumpelly in conjunction with Major T. B. Brooks published a paper entitled, "On the Age of the Copper-bearing Rocks of Lake Superior."* They state that their observations "demonstrate a wide difference in age between the Cupriferous series of sandstones, conglomerates, and melaphyres on the one hand, and the Lower Silurian sandstone, with which they have generally been considered as nearly identical in age, on the other." At the western edge of the eastern sandstone on Keweenaw Point "its nearly horozontal strata abut against the steep face of a wall formed by the upturned edge of beds of the Cupriferous series of melaphyre and conglomerate, which dip away from the sandstone at angles of 40° – 60°, according to geographical position. This sharply defined and often nearly vertical plane of contact, having been seen by the earlier geologists at several points along a distance of many miles, and having been found to be often occupied by a thick bed of chloritic fluccan, which was looked upon as the product of faulting motion, was considered as a dislocation. This idea seemed to gain corroboration in the fact that, on the western side of Keweenaw Point, sandstones bearing considerable resemblance to those of the eastern horizontal beds occur, apparently conformably overlying the Cupriferous series. Both sandstones came to be considered as identical in age, and as forming the upper member of the group. There were many circumstances which made it difficult for us to accept this conclusion. One obstacle lay in the enormous amount of dislocation required; for instance, at Portage Lake, where the strata of the Cupriferous series, with an actual thickness of several miles, dip away from the supposed *longitudinal* fault at an angle of about 60°." The Cupriferous series is regarded by them as conformable to the Huronian, while the line of fault is taken to be an old shore cliff, with the sandstone deposited against its base. They also state that it would be difficult to account for the absence of this series in localities eighteen miles from where they were found miles in thickness, unless they represented a sinking area along whose shores the Silurian sandstone was deposited. They also claim that this series was worn through near Lake Gogebic, and the Silurian sandstone deposited in the trough. It is to be noticed that according to them the Cupriferous series are four miles distant from the locality in which the Silurian sandstone is said to have been seen. Their geological reasoning could only hold good in a region where uncontorted sedimentary rocks *alone* occur; therefore we are justified in believing that at this time both Pumpelly and Brooks regarded the copper-bearing traps as metamorphosed sedimentary rocks. We are not aware that the latter has ever changed his views.

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* Am. Jour. Sci., (3,) III. 428 – 432, 1872.

In 1873, Dr. T. Sterry Hunt* used the term *Keweenian group* in speaking of the copper-bearing rocks, and suggests that perhaps the copper may have been derived from the oxidation of copper ores in the Huronian schists, while the dissolved metal accumulated in the basins at their base, — a view almost identical with that announced by Shepard twenty-eight years before. "We may here remark that the late researches of Messrs. Brooks and Pumpelly seem to establish that the great copper-bearing series of Keweenaw occupies a place between the Huronian schists and the nearly horizontal red and white sandstone of the region which is itself below the Trenton limestone. In all this they have confirmed the previous conclusions of Houghton, Whitney, Hall, and Logan." It may be remarked here, also, that if Prof. Whitney's writings have taught anything, it is that the sandstone from Sault St. Marie to the further side of Keweenaw Point, including the copper-bearing rocks, are one and the same formation; therefore Dr. Hunt's statement is incorrect in this particular at least. In proof of this, one can read his own statement of Prof. Whitney's ideas on page 79 of the "Azoic Rocks." † As we have shown before, Houghton regarded the copper-bearing rocks as eruptive in, and therefore younger than, the sandstone of Keweenaw Point, which in 1843 he took as belonging to the "New Red." This is the last published statement that we can find of Houghton's on this point.

Mr. Brooks, in his Report on the Iron Districts of Lake Superior, ‡ regards it as proved that the copper-bearing rocks are conformable with the Huronian; the proof was obtained, not from contacts, but from their common dip and strike. He also states: "Against and over the copper series on the north, abut the horizontally bedded lower Silurian sandstones. . . . . As the *non-conformability* of the copper-bearing rocks and sandstones is doubted by some geologists, it should perhaps be stated that the actual contact was not seen. But the sandstones were observed lying horizontal, and affording not the slightest evidence of disturbance, within a few miles of highly-tilted copper rocks, which gave every evidence of having been elevated before the deposition of the sandstones. So far as my observation has extended, this rule is general; that is, no Lake Superior sandstone, which is unmistakably lower Silurian, has ever been found in any position other than nearly horizontal";—Will Mr. Brooks visit Presque Isle?—"and no rock which was unmistakably of the Copper series has been seen which was not considerably tilted. The fact that certain sandstones belonging to the copper series are very similar, if not lithologically identical with some of the lower Silurian sandstones, has helped to complicate this question. An interesting locality for study in this connection is the west fork of the Ontonagon River, just south of the Forrest Copper Mine. I am not sure but that it affords an exception to the rule above stated, as at that point sandstones, *apparently* Silurian, dip south at an angle of 45°."

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* Trans. Am. Inst. Min. Eng., I. 331 – 342.

† Sec. Geol. Survey of Penn. E, Azoic Rocks, Part I.

‡ Geol. of Mich., I. 184, 185.

In Prof. Pumpelly's Report of the Survey of the Copper District,* we find but little written by him of geological interest excepting that which had been published elsewhere, and referred to in the preceding pages.† The sandstone beds on the eastern side of Keweenaw Point are said to slope gently to the southeast (*l. c.*, p. 1). The chief portion of the geological work, and about all of any value, seems to have been done by Mr. A. R. Marvine, who, judging from his work, appears to have possessed the power of observing well and accurately in the field. Only certain portions of his work can be pointed out here: "The conglomerate beds of Keweenaw Point have been generally considered as mere local deposits, rapidly fading out in either direction. The table would seem to show, on the contrary, that for conglomerates they are unusually persistent, and that while a bed may thin out and lose its character as a conglomerate, it may still exist even as a mere seam. . . . . We gather from those facts that when the beds composing the trappean range were being originally formed, the agencies, whatever they were, which formed what are now the melaphyrs, ceased to act not only over limited but over extended areas, in one instance at least over fifty (50) miles, and for periods of time long enough to allow of the accumulation of beds of conglomerate from a few to over 75 feet — in one instance over half a mile — in thickness." (*l. c.*, pp. 60, 61.)

Mr. Marvine points out the fact that much of the amygdaloidal character of these rocks is owing to chemical action upon approximately homogeneous rock long after it was formed, and "the amygdules which mark this change were thus slowly developed, and are not the mere fillings of pre-existing cavities." Besides this pseudo-amygdaloidal structure true amygdaloidal structure was also pointed out. Concerning the sedimentary origin of these rocks he remarks: "But the strongest proof would seem to be in the structure of the so-called scoriaceous amygdaloids. In these, patches or balls of amygdaloidal material are associated, even surrounded by an imperfectly stratified material, which is undistinguishable from the true fine-grained sandstones. This association is such that it seems as if it could in no wise be accounted for by metamorphism acting on sedimentary beds, but only by supposing a peculiar mixture of the materials at the time of deposition, which mixture is not such as sediments assume. . . . . The fact that in sandstones which are intercalated between two trap beds the upper parts, for several inches from the hanging wall, are often changed as if by heat, while at the bottom contact there is no such change, cannot be offered as an objection to the metamorphic theory, for it would be in just such regions that metamorphism would naturally occur. But the fact that sandstone material seems to have entered amygdules near the upper part of beds covered by sandstones; that it may fill a well-defined crack extending down into an underlying melaphyr, ... or that melaphyr may nearly surround pebbles apparently caught up from an underlying conglomerate . . . . ; these facts, as does the peculiar structure of the scoriaceous amygdaloids above noticed, seem to point to a very different origin for the melaphyrs than a sedimentary one. . . . . As a whole, then, the *structural* features of these beds remarkably resemble those of true lavas. They have been affected, however, and to a very great extent, by metamorphism, and this metamorphism has taken place in such a manner, has so heightened and carried on the original structure, as it were, that the ordinary proof of their igneous origin, such as contact changes in adjacent sandstones, presence of amygdules, etc., fail, and it seems natural to consider this metamorphism as a *vera causa* for the whole structure. Certain extraordinary features, however, as noticed above, seem wholly incompatible with this idea, and when considered as true igneous rocks in which great and peculiar metamorphism has taken place, all the phenomena presented seem to be satisfactorily and naturally accounted for. . . . . These changes, however, have been both very many and very great; so great, in fact, that, as seen above, when once examined they seem almost sufficient to have developed all the peculiarities of the beds from sedimentary deposits. The practical importance of the recognition of this metamorphism and of a proper understanding of its methods and effects, will be apparent when it is recollected that to it is due all the economical value the beds possess. The beds as originally formed probably contained the elements of its minerals, together with its copper and silver, more or less disseminated through their mass, as much so remains till the present day, or else they were so contained — at least in part — in overlying rocks, and in this form they could have been of no economic value; nor could any process taking place at that time have concentrated the minerals in the manner in which they now occur." He opposes the theory that the copper was deposited in its present position by igneous action.

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* Geol. of Mich., Part II., 1873.

† Am. Jour. Sci., 1872, (3,) II. 188-198, 243-258, 347-355; III. 428-432.

The metamorphic action is thought to have resulted from the agency of percolating waters. "All the phenomena tend to prove that it is by means of some such chemical actions as these, continued through long periods of time, that the metamorphism of these beds has been effected. It is such metamorphism which has developed the amygdaloidal melaphyrs, formed segregations, modified and filled the veins and amygdules, placing in them their minerals in the present relative positions; and, in the general process, the copper, like the other ingredients, was selected from its disseminated and therefore useless condition, and concentrated in veins, amygdaloids, and conglomerates till it reached a percentage of richness that gives to the deposits an economical importance. This action has taken place certainly not at a high temperature, and possibly at a temperature no greater than that of the beds at present, while it may have been largely aided by that electric action which chemistry almost always induces, and which is known to be active at the present day. In fact the presence of the latter is proof that chemical action is even yet going on. . . . .

"Where observed, the hanging-walls of the sandstones were generally smooth and gently undulating, but occasionally quite uneven, while the upper two to twelve inches were somewhat changed, being harder or softer, or lighter or darker-colored than the mass of the bed. . . . . The foot-walls are sometimes smooth and undulating; the surface of the underlying bed, when not an amygdaloid, as was sometimes the case, seeming to have been worn smooth, as if by attrition; or else the sandstone seemed to fill inequalities in the underlying amygdaloid. The sandstones were not observed to be changed near the foot-wall. In one remarkable instance, a crack or fissure was observed extending down into a melaphyr, which was filled by the overlying sandstone. The conclusion is inevitable, that the melaphyr had formed, hardened, and cracked before the sandstone was deposited. . . . .

"The veins of the district were of course formed long after the consolidation of the beds, and probably when they were being lifted into their present position. They have subsequently been filled with the various minerals which now occupy them, wholly by infiltration and chemical, probably aided by attendant electric, action, and in a systematic and natural sequence." (*l. c.*, pp. 108 – 115.)

Regarding the junctions of the sandstone and amygdaloid in two localities he says: "*Junction*, very irregular. For two feet the underlying sandstone is changed and indurated, being, in places, hardly distinguishable from the overlying melaphyr, except for enclosed pebbles which are not changed. Some pebbles rest upon the hanging-wall, which are quite enclosed in the overlying amygdaloidal melaphyr. . . . . *Junction*, slightly undulating. No change or metamorphism in the adjacent beds. Extending from the junction down into the underlying melaphyr — about eight feet being exposed — is a fissure or crack with sharply defined edges and two abrupt bends, giving widths of two and four inches. This crack is filled with sandstone similar to that above, but somewhat finer and slightly decomposed or softened. There is an appearance of irregular, but rudely curved stratification, about parallel, as a whole, with the formation." (*l. c.*, pp. 118, 119.)

It is to be seen, then, that Mr. Marvine arrived at the same conclusions regarding the Copper-bearing rocks as did Messrs. Foster and Whitney, and supported these views by the same evidence that they had more fully and thoroughly given in their report.

In Part III.* we have the report of Dr. C. Rominger on the Palæozoic Rocks. Regarding the sandstone he says: "The lower Silurian age of the Lake Superior sandstone is unequivocally proved by its stratigraphical position. In its whole extent it is visibly overlaid by calcareous ledges, containing fossils peculiar to the Calciferous formation, or, in other cases, by the Trenton limestones. The recognition of a separate rock-series, identifiable with the Calciferous formation, at once nullifies the other mentioned opinions of Geologists, and leaves no choice but to see in the Lake Superior sandstone the equivalent of the Potsdam sandstone. . . . . The thickness of the Sandstone formation is difficult to ascertain. Its lower portions are so intimately connected with the sandstones and conglomerate beds of the copper-bearing Trappean series, that I could draw only an arbitrary division line between the two groups, which would swell the thickness of the sandstone group to many thousand feet, while east of the Copper range, the whole sandstone series reposing on the Huronian and Granitic rocks does not exceed the thickness of 300 feet." (*l. c.*, pp. 80, 81.)

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* Geol. of Mich., I. 1873.

"The sandstones lining the eastern shore of Keewenaw Point extend approximating to the centre of the Peninsula, retaining their horizontal position, and also their lithological characters to such a degree that the different strata can be parallelized without difficulty with those of the more eastern localities. Near the centre the horizontal sandstone ledges are found at once abutting against the uplifted edges of a different rock-series — the *Copper-bearing rocks* — which form the most elevated central crest of the Peninsula." (*l. c.*, p. 95.) "The discordance of the strata on the east side of the axis of elevation, and their conformability on the sloping west side, finds its explanation in the hypothesis of a gradual submarine upheaval of the trap range, in its subsequent rupture, and the final emergence of the western margin from the water, while the eastern portion of the fissured earth's crust remains submerged." (*l. c.*, p. 98.)

In 1874, Prof. Roland Irving discusses the question of the age of the copper-bearing rocks of Wisconsin, which were regarded as identical with those of Keweenaw Point. He advocates the same views as those held by Pumpelly and Brooks, and bases his conclusions on similar grounds. The Laurentian, Huronian, Copper-bearing rocks, and Lower Silurian sandstones were never seen in direct contact with one another with one exception. That exception is the junction of a trap supposed to belong to the Copper-bearing series with the Potsdam sandstone. The sandstone, he states, is for three hundred feet from the trap "broken in every conceivable manner, the misplaced layers dipping in all directions, and in its immediate vicinity making a sort of brecciated mass of fragments of trap and sandstone. . . . . These trappean beds carry here *no intercalated beds of sandstone and conglomerate.*" He objects to the most probable explanation in this case, the protrusion of this trap through the sandstone, as the trap seems to be unlike the Copper-bearing rocks, except in the fact that it is an old basalt; but thinks some deep-seated force shoved the old formation, on whose flanks the sandstone was deposited, upwards, and so produced this dislocation.*

Concerning the relation of the western sandstones to the eastern and to the trap rocks in the Ontonagon district, Dr. Rominger says: "The age of these beds is intermediate between the trap and the horizontal sandstone deposits; but between all three of the indicated groups so great lithological affinities exist, that it is most natural to consider them as the consecutive products of one and the same epoch, in the commencement of which the just-formed strata were displaced by volcanic action, which subsided toward the end and left the last deposits undisturbed." *

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* Am. Jour. Sci., (3,) VIII. 46-56; Trans. Wisc. Acad. Sci., 1873-74, II. 107-119.

In 1878, Prof. Pumpelly published a paper entitled the "Metasomatic Development of the Copper-bearing Rocks of Lake Superior." † This is devoted principally to a description of the microscopic characters of these rocks and their alterations, and, although we differ in nomenclature, we regard it as one of the very best papers published upon microscopical lithology. His geological ideas remain the same, however, as he states that the greater age of the Keweenaw series over the Potsdam sandstone is proved by abundant evidence of non-conformability. He regards them "more nearly conformable to the underlying highly tilted Huronian schists. They are thus the product of the earliest eruption of basaltic rocks to which a proximately definite age can be assigned. They were preceded by very extensive eruptions of acid rocks, especially porphyries. These basaltic rocks have been subjected to a wide-reaching alteration, which has produced marked changes in the internal condition of the beds, and has filled the fissures with a rich variety of minerals, whose constituents were derived from the products of this alteration. (*l. c.*, pp. 253, 254.) These old basaltic rocks were considered to be melaphyrs and diabases.

It is to be seen that he now adopts the views of the origin of the traps held by Messrs. Foster and Whitney, and later by his assistant, Marvine. The reasons for this radical change of base are not stated: we have simply the assertion that the traps are basaltic overflows, made as though no one had ever held a different opinion.

Later, Dr. T. Sterry Hunt says that it seems probable from our present state of knowledge that the traps are of volcanic origin. He regards them as unconformable with the Huronian, as he takes the Copper-bearing rocks as the equivalent of his Taconian. This, of course, requires the intercalation of his Montalban between them and the Huronian. ‡

Dr. J. D. Dana in his Manual of Mineralogy and Lithology, § says concerning the occurrence of the native copper with disseminated silver: "This mixture of copper and silver cannot be imitated by art, as the two metals form an alloy when melted together. It is probable that the separation in the rocks is due to the cooling from fusion being so extremely gradual as to allow the two metals to solidify separately, at their respective temperatures of solidification — the trap being an igneous rock, and ages often elapsing, as is well known, during the cooling of a bed of lava, covered from the air." We may remark here that Hunt's edition of Ure's Dictionary, 1878, states that the West Canada copper mines are the most important in America. Such carelessness of statement should hardly be allowed in a work of its purported character.

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* Geological Survey of Michigan, 1873-1876, III. 154.

† Proc. Am. Academy, XIII. 253-309.

‡ Sec. Geol. Survey Penn. E, Azoic Rocks, Part I. p. 236.

§ New York, 1878, p. 131.

Mr. A. R. C. Selwyn, in the Canadian Naturalist,* opposes the use of the numerous names based upon purely theoretical lithology; i. e. Norian, Montalban, Taconian, Keweenian, etc., in the crystalline rocks. He includes the Copper-bearing rocks in the Huronian. His views, however, were objected to by Mr. Thomas Macfarlane.† Mr. Selwyn's paper was again published in the Report of Progress of the Canada Geological Survey for 1877 – 78 (A, 15 pp.).

In the third edition of Prof. J. D. Dana's Manual of Geology (p. 778) we are given his views concerning the deposition of the copper at Lake Superior as follows: "When eruptions of melted rock have taken place, they have often brought not merely the heat of great depths to the surface, but also, various mineral materials encountered on the way up, and especially some of the metals or their ores.

"The fissures were in general deeper than those that gave origin to veins of segregation, for the latter did not reach to where melted rock could fill them, and hence had to be filled by what they could get through the slower process. They consequently must have descended to regions of very high temperature. As in a volcanic conduit, whatever at these depths, in the heated subterranean region adjoining the opened passage-way, was ready to pass into a state either of vapor or liquidity, would have been forced, by the pressure to which it was subjected at those depths, to escape, if possible, by the way made for the liquid rock, and would have ascended either along side of the latter, or within its mass; and at the same time, a portion would have been liable to be forced into the wall rock of the fissure wherever it was not of too close a texture to receive it. The mineral material that could take advantage of such an opportunity, or be aided in it by the heat of the ascending melted rock, would be that, as just implied, which was most easily fused or vaporized; and this includes certain metals and their ores, especially those of copper, silver, and antimonial, arsenical, and sulphurous ores of lead, or of lead with silver or copper. The fusing points of pure copper and silver are below 2,500° F., that of copper being, according to Riemsdyk's experiments, at the Utrecht mint, in 1869, 2426° F. and that of silver, 1904° F.; and hence these might have passed into the melted rock in the liquid state; but whether this was the fact, or whether they were in vapor, or in some vaporizable or soluble compound, is not definitely known.

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* 1879, (2,) IX. 17 – 32.

† Remarks on Canadian Stratigraphy, Can. Nat. and Geol., (2,) IX. 91 – 102.

"The above is a general explanation of the initial movement in the making of copper mines like those of Lake Superior, in which the metal is in the native state, and the silver mines of Nevada, Mexico, Bolivia, Chili, Transylvania, and of many other regions, which afford various ores of silver with often some native silver. The igneous rock of the Lake Superior region is largely doloryte, and copper is in fissures and cavities in the igneous rock, and in the sandstone of the walls."

In the third volume of the Geology of Wisconsin the copper-bearing rocks are regarded as older than the sandstone, but younger than the Huronian. The traps, with their associated sandstones and conglomerates, are called the *Keweenawan series*, while the supposed unconformable sandstone is regarded as Potsdam. The evidence advanced is good, so far as it goes, but it proves nothing until it shall be shown that the old basalts studied in each particular case are not dikes, but overflows identical in age with those on Keweenaw Point, and that they are not earlier or later eruptions. In this respect the strongest evidence advanced by the Wisconsin geologists is fatally defective. Their methods of observation fail in giving the proof necessary to establish their conclusions, which may or may not be correct, so far as their work goes.

Historical Summary.

The theories advanced concerning the Copper district are so various and conflicting, in many cases even in the writings of the same author, that we cannot hope to do justice to them in a brief summary.

The principal points to which we have directed attention thus far are: 1st, the origin of the traps and their interbedded sandstones and conglomerates; 2d, the relation that the traps bear to the eastern and western sandstones; 3d, the age of the eastern sandstone; 4th, the origin of the veins and the copper deposits.

Concerning the origin of the traps, it has been seen that they were said to be in dikes, generally intruded through the series of sandstones and conglomerates, by Houghton, Jackson, Shepard, Hubbard, and Marcou. They were thought to be in lava overflows by Hubbard, Foster and Whitney, Jackson, Bigsby, Hall, Hunt, Pumpelly, and Irving. They were regarded as metamorphosed sedimentary rocks by Locke, Rivot, Pumpelly, and Brooks, while the amygdaloidal portion was said to have been formed from fused sandstone by Houghton and Jackson, and from sedimentary material, possibly volcanic mud, by Hunt. The latter author at first taught that the traps were eruptive, but separated the amygdaloids from them.

The traps were supposed to be of a prior age to the sandstones by Bayfield (who thus long antedated the views of Pumpelly and Brooks), Logan, Whittlesey (who regarded them as conformable with the sandstones), Alexander Agassiz, Pumpelly, Brooks, Hunt, Rominger, Irving, and Selwyn. They were said to be younger than the sandstone by Houghton, Jackson, and Marcou. They were taken to be of the same geological age as the sandstones by Hubbard, Foster and Whitney, Jackson, Bigsby, Rivot, Logan, Hall, Dana, Pumpelly, Hunt, and Rominger.

The traps were assigned to a geological age distinct from the eastern sandstone, and given the name *Keweenawan* by the Wisconsin geologists, *Keweenawian* by Brooks, and *Keweenian* by Hunt. Logan and Selwyn assigned them to the Huronian, the latter doing so principally on account of the erroneous observations of Pumpelly and Brooks.

The eastern sandstone of Keweenaw Point was regarded as Old Red by Bayfield and Bigsby; as New Red, by Houghton, Ruggles, Jackson, H. D. Rogers, Shepard, Owen, Marcou, and Dana; as Potsdam, by Hubbard, Foster and Whitney, Owen, Logan, Hall, W. B. Rogers, Rivot, Rominger, and Irving; as partly Potsdam and partly Calciferous, by Logan and Dana; as Calciferous, by Dana; as Chazy, by Logan; as Quebec, by Logan, Hunt, and Pumpelly; as Permian, by Macfarlane; and as Permian or Triassic, by Bell. The sandstone was also thought to be older than the Potsdam by Logan and Whittlesey.

Dr. Houghton at first regarded the sandstone and trap from the Sault St. Marie to the Porcupine Mountains as the same formation; later, he thought that the sandstone west of Grand Island was unconformably overlaid by that east of that island; still later, the sandstones east of Keweenaw Bay were said to be older than the Trenton, while the Copper-bearing rocks were thought to be New Red.

The veins were thought to have been formed anterior to the traps by Jackson, and at the time of their eruption by Dana and Marcou, but by the majority of the observers posterior to the consolidation of the entire series of rocks. They were believed to have been filled by injection by Houghton, Ruggles, Jackson, Agassiz, and Marcou; by injection and sublimation, by Hodge; by sublimation, by Houghton and Jackson; and in the wet way, by Foster and Whitney, Rottermund, Müller, Bauerman, Dawson, Pumpelly, Marvine, Hunt, and others. Houghton regarded the district as identical with Cornwall. The copper was supposed to have been thrown from volcanoes by Schoolcraft, while H. D. Rogers and Dana teach that it was deposited during the cooling of the trap. Ruggles, Agassiz, and Marcou regard it as injected in dikes from the molten interior, while Bauerman and Pumpelly teach that it was originally deposited in the sandstone from the sea-water through the reducing agency of organic matter. This view seems to be shared by Hunt, who likewise, in common with Shepard, thought that copper was derived from the *débris* of ores in the older rocks, and deposited in the sandstones. Prof. Shepard thought that it was concentrated from the sandstones, and brought to the surface by the action of the traps. Whether Dr. Hunt teaches that the copper was derived directly from the sandstones and deposited in the veins, or was brought up by the extravasated traps, which, according to his theories, must have originally formed the lower portion of the Keweenawan series, and was thence concentrated in the veins, we cannot tell, for, [illegible] is frequently the case in his writings, his English admits of more than one construction. Müller, Bauerman, and Marvine think that the copper may have been an original constituent in the traps in a finely divided condition. Prof. Dana teaches that it was derived from ores in the older rocks by the action of the traps, and holds, with Houghton, Jackson, and Shepard, that it was brought up by the trap. Foster and Whitney, Dawson, Müller, Bauerman, Pumpelly, Marvine, and others, would refer the concentration to electro-chemical action. Benjamin Silliman, Jr., and Jackson said that the copper and silver, when found joined, had been fused together; while Hodge explained the phenomenon by supposing that the copper was injected first, and by its contraction left vacant spaces into which the silver was injected later. Such, in brief, are some of the various theories advanced.

The Traps.

In order to ascertain the origin of these rocks, we have to examine, first, their relation to one another, and, second, to the interlaminated sandstone and conglomerate.

The relations of these rocks can be well studied in an adit about one mile long, extending from the western sandstone through alternating beds of sandstone, conglomerate, and trap, to the ash-bed at the Copper Falls mine. We find here that the sandstone, when underlying the trap, has its upper portion adjacent to it baked and indurated; showing the usual characteristics of a ferruginous sandstone when subjected to a certain amount of heat. This indurated sandstone has frequently been subjected to secondary water action since it was buried under the trap, and hence has lost some of its hardness and other signs of baking. No fragments of the trap were found in the immediately underlying sandstone, but tongues of trap extend down into it in some places, and indurate it. The surface of the trap underlying the sandstone is water-worn, forming smooth, rounded knobs and irregularities, upon which the sandstone was deposited. The immediately overlying sandstone shows none of the baking and induration that the underlying one does. In no case, so far as we saw, was there any difficulty in separating the sandstones or conglomerates from the traps. The upper side of the sandstone was especially distinctly separated from the overlying trap, while on the under side, on account of the composition of the sandstone, the junction was not so obvious. While the trap always affected its underlying sandstone, and frequently included masses of it, in no case did it produce any effect on the overlying one. The sandstones or conglomerates at their base contain fragments and pebbles of the underlying trap; but this detritus diminishes as we recede from the trap, and is generally wanting after a thickness of two or three feet has been laid down. The trap is found to be cellular and amygdaloidal on its upper side, but on the lower to be compact and more coarsely crystalline. If the traps had been intrusive between the beds of sandstone, both the upper and underlying sandstone would be alike affected adjacent to the trap. If the trap was formed from the sandstone metamorphosed *in situ* there ought to be some gradual passage between the two, and the fragments of sandstone enclosed in the trap should more especially show such passage. On the contrary, nothing of the kind could be found, but the sandstone fragments were greatly indurated, and the traps adjacent to them filled with quartz (646, 647, 648). Specimens 469, 478, 479, 480, 482, and 483 from the Calumet and Hecla, and 621 from the Copper Falls mine, are examples of the contact of the sandstone with the underlying trap, and 477 and 478 from the Calumet and Hecla, and 577, 578, 579, 610, 611, 612, 613, and 620 from Copper Falls, show the contact with the overlying trap. The only explanation of these facts, which were first pointed out by Messrs. Foster and Whitney, and later by Mr. Marvine, is that given by them, that the traps are lava flows, and that they were successively laid down upon one another, or covered by sandstone and conglomerate. They are seen to have the same characters, except so far as they have undergone secondary changes, that modern basaltic lavas have. These old basalts have been denominated melaphyrs and diabases by Prof. Pumpelly, to whom lithologists are indebted for their knowledge of their microscopic characters. While we would use the terms that Prof. Pumpelly has, we object to the application he has made of them. Many of his diabases we should call melaphyrs, and many of his melaphyrs we should class as diabases. We of course differ in our definitions of these terms, for while he would regard melaphyr and diabase as distinct rock species, we hold that they are only altered forms of basalt. The greenstone ridge back of the Cliff and Phœnix mines we regard as an excellent example of diabase (791, 792), with which we class all the heavy-bedded crystalline traps of that region, while the thin-bedded scoriaceous or amygdaloidal highly altered traps we class as melaphyr, but in the majority of cases Prof. Pumpelly regards them as the reverse. The diabases are rarely if ever mined, the melaphyrs frequently.

In a recent paper "On the Carboniferous Volcanic Rocks of the Basin of the Firth of Forth — their Structure in the Field and under the Microscope,"* Prof. Geikie points out the difference microscopically between lava flows and intrusive masses, and evidently thinks that they can always be as readily separated in the cabinet, microscopically, as they can be in the field. While it is doubtless true that this separation can be made in the rocks studied by Prof. Geikie, his distinctions fail in the Lake Superior district. The difference in structure pointed out by him seems to be entirely owing to the rate of motion and pressure at the time of crystallization, and the rapidity with which the lava solidified. When lava flows in thin sheets, or, if we confine our examination to the upper portion of a thick sheet, we find characters that readily distinguish the sheets from the dikes; but when we come to study the middle and lower portions of the thick sheets, where there was little or no motion combined with the pressure of the overlying mass, the rock is undistinguishable from rock of the same composition in dikes; and the diagnostic characters given by Prof. Geikie would assign it to an intrusive rock, not to an overflow. In the before-mentioned Emerson adit at the Copper Falls mine, some melaphyrs were seen that were apparently in the form of dikes intruded since the lava flows (624, 626, 627, 628).

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* Trans. Royal Soc. of Edinburgh, XXIX. 437–518.

The form of lava locally known as "ash-bed" has attracted considerable attention. It has been described in various ways, generally being regarded as fused sand and trap. Latterly Prof. Pumpelly has described this as "volcanic scoriæ buried in the littoral sand."* At the present time the ash-bed can be best studied at the Copper Falls mine, where it is largely mined for the copper it contains. After a careful study of it, we conclude that the ash-bed is a very scoriaçeous, and, comparatively speaking, somewhat thin lava flow. It does not possess the ordinary characters of the other flows of Keweenaw Point, but seems to be largely made up of clinkers and scoriaceous masses. It appears to have flowed in a more or less fragmental condition, forming a black, rough, loosely aggregated, scoriaceous, cinder and lava sheet, similar to those described by Prof. Whitney in his "Report on the Geology of California," † and by Prof. Palmieri in his "Account of the Eruption of Vesuvius of 1871-72."‡

At the time of the flow, or since, the interstices were filled with detrital mud. The various parts of the flow seem to be connected in the main, and do not form to any great extent true pebbles.

That the rounded fragmentary portions derive their structure from the cooling of a fluid mass, and not by water action on the melaphyrs, is shown by their cellular structure in the interior, and solid crust on the exterior, the same as similar modern lavas have. Water-worn pebbles of melaphyr, as seen at some of the old burrows of the Hancock mine in a detrital deposit (832, 833), which to the casual observer resembles the ash-bed, have the cellular structure extending throughout the mass, and are destitute of any crust.

The same flow exists at the Petherick and Old Phœnix mines, while a similar formation is mined at the Atlantic. Besides the true ash-beds, there seem to be confounded with them certain sedimentary deposits composed of rounded water-worn pebbles of melaphyr held by littoral sand. These forms pass into a more siliceous conglomerate or sandstone, or not, according to the length of time that elapsed before the succeeding flow. They are abundant west of Houghton, and, so far as I could find, are the only formations existing at the Hancock mine that could have led Prof. Pumpelly to state that an ash-bed was worked there.* Specimen 814 is a good example of the end of a lava mass, which still retains its original ropy and fluidal surface structure. This came from the ash-bed at Copper Falls, and gives conclusive evidence that it had never been water-worn. Tongues of the ash-bed were seen extending down into its underlying trap, while the overlying trap sends tongues down into the ash-bed (Fig. 27).

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* Proc. Am. Acad., XIII. 283.

† 1865, Vol. I. p. 267.

‡ Annali del reale Osservatorio meteorologico Vesuviano, (Napoli, 1873,) p. 28. The same, translated by Robert Mallett, (London, 1873,) p. 103.

From their nature all the various lava flows are liable to be limited in any direction, either from their thinning out, the flow meeting obstructions, or from denudation since deposition, but before being buried under conglomerate or the succeeding flow. They were evidently poured out on a shore line, whose position probably varied relatively to the traps. The intervals between the different flows seem to be brief in some cases, while in others considerable time must have elapsed. Figure 28 shows the relation of the trap to the sandstone at one point in the Emerson adit at Copper Falls, exhibiting the irregular surface of the latter before the lava flow.

The Sandstones and Conglomerates.

As we followed the Hungarian River, a tributary of Torch Lake, upward, starting from the low sandy plains near the lake, the sandstone was first observed forming high bluffs on both sides of the river, and dipping N. 45° W. 10°. It occurs in coarse and fine layers often enclosing pebbles. As the river is ascended the layers of pebbles were seen to curve in various directions with an irregular dip, but which in general inclined to the northwest. Some of the pebbles appeared to be of quartzite similar to that at Carp River, Marquette (522). The Hungarian Falls are formed by the river being precipitated over several ledges of the sandstone and conglomerate. Several specimens were taken, showing the different varieties of pebbles composing the conglomerate (523, 524, 525, 526, 527, 528, 529, 530). No. 523 is an old trachyte composed of a reddish-brown groundmass, holding white kaolinized feldspars, dark brown decomposed hornblende crystals, and a little mica. It is closely allied to some of the modern rocks from the Cordilleras. The groundmass is now kaolinized, forming a dirty-white mass holding secondary quartz and feldspar, as well as long narrow ferrite masses. These latter appear to have been formed from the hornblende fibres, so frequently seen in the allied rocks from the Cordilleras. The groundmass has now through its alteration a spherulitic structure.

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* Proc. Am. Acad., XIII. 283.

No. 524 is a more compact rock of like character. Its groundmass is kaolinized and holds the quartz and feldspar alteration products. It is filled with grains and masses of ferrite probably derived from hornblende. The feldspar is so decomposed that it cannot be told whether it is plagioclase or orthoclase. Nos. 526 and 529 are like No. 523, while No. 530 is more allied to No. 524.

No. 527 has a more coarsely crystalline, granitoid structure, showing under the lens a reddish and grayish brown groundmass, holding elongated brownish-black hornblende crystals. In the thin section it is seen to be composed of feldspar, magnetic iron, hornblende, and some quartz. The feldspar is greatly altered, and is now composed of intergrowths of feldspar and quartz, giving rise in it to a structure resembling that of graphic granite, or much of that figured as belonging to the Eozoön Canadense. The quartz is all secondary, and the hornblende altered to reddish or yellowish brown ferruginous masses.

No. 528 is a fine-grained granitoid trachyte (granite porphyry), but in the thin section the feldspar is seen to be so altered and filled in with secondary quartz, containing full and bubble-bearing fluid, and vapor cavities, that the section resembles that obtained from some fragmental rocks. No. 525 is a rock of similar character.

Nos. 538, 539, 541, and 544 are good examples of some of the sandstones on the river below the melaphyr. No. 538 is seen in the section to be composed of quartz and trachytic detritus.

Below and at the base of the falls the dip remains the same as before, N. 45° W. 10°, but above this locality the inclination varies, rising from 15° to 18° between the first and second falls. In some places a quaquaversal dip was seen. Some five falls exist in the river, and at the last or upper fall the melaphyr was found. The dip of the sandstone has now increased to some 20°, but still dips northwest, and the first trappean flow is seen to overlie and greatly indurate and alter it. This immediately underlying sandstone (537) is filled in with little reticulated veins of calcite, a kaolin-like material, etc., and in general resembles the baked sandstone found underlying the trap on the western side of Keweenaw Point. Microscopically, it is seen to be composed of the *débris* of the trachytes previously described. This sandstone was seen within three inches of the melaphyr, and although there may have been some sliding motion between the two, as the contact was not seen, yet the induration of the sandstone, its dip, and its relations to the melaphyr, prove that it underlies the latter, which flowed over it. This, then, with evidence obtained on the Douglas Houghton River, settles the long-disputed question of the relative age of the traps and eastern sandstones of Lake Superior. The dip of the melaphyr is about the same as that of the sandstone. Immediately above this thin lava sheet, a conglomerate comes in, forming the fifth fall. The base of this conglomerate is composed of a fine-grained detritus formed from the melaphyr and trachyte, and holds numerous pebbles of the melaphyr, as well as of the other rocks (531, 532, 533, 534, 535, 536). Immediately overlying this conglomerate is another melaphyr flow, and we have here on the eastern side a repetition of the same alternate bands of melaphyr and sandstone that occur on the western side.

It is to be remembered that Mr. Agassiz, in conjunction with Mr. L. G. Emerson, the well-known mining engineer of Hancock, and at one time assistant on Prof. Pumpelly's geological survey, found below the Douglass Houghton Falls pebbles of the melaphyr (amygdaloid) in the sandstone; and from this the conclusion was drawn that the sandstone was younger than the trappean formation. At the time of our visit to this locality, we had no knowledge of Mr. Agassiz's observations,* except from the general statement of Prof. Pumpelly.† It will be seen that no localities were given by Prof. Pumpelly, although he confirms Mr. Agassiz's statements. The falls were said by Mr. Agassiz to be located at the junction of the sandstone and trap, while on both sides of the ravine the horizontal sandstone beds were traced up to the falls. Our examination showed that immediately below the falls sandstone and conglomerate exist, dipping N. 45° W. 25° (504, 505). While the majority of pebbles were of the usual character, one grayish granitoid pebble (506) containing epidote was obtained. This has suffered the same *graphic* alteration in its feldspar that No. 527 has. Much of the feldspar is seen to be triclinic. Otherwise than its containing more quartz, its characters are in the main like No. 527. The sandstone, at its junction with the overlying trap, is much indurated and altered, and specimens were obtained showing the junction of the two (507, 508, 509, 510, 511). As the sandstone underlies the trap, it is of necessity the prior-formed rock. We suppose that this was the locality at which Messrs. Agassiz and Emerson obtained their specimens of melaphyr in the conglomerate. If so, it is easily enough explained, for conformably underlying this sandstone is another sheet of melaphyr, then more sandstone, again more melaphyr, and so on, all conformably underlying one another as much as they do anywhere within the trappean belt, or can do, on account of their origin. Whether this is the spot or not, it is evident from the language of Mr. Agassiz's paper that the gentlemen took their facts and drew their conclusions while they were within the trappean belt, not having found the junction at all, it being some distance below the falls, not at them. From Prof. Pumpelly's statement it would seem that he had made the same mistake, as likewise Mr. Foster had done years before.* Something more is necessary to be observed than simply to find a sandstone or conglomerate on the eastern side; it is necessary to prove that it is part of the eastern sandstone, and not a bed intercalated in the trap. The sandstone and melaphyr, a short distance below the dip last given, has a dip of 20°, still inclining to the northwest. The last melaphyr sheet underlies a sandstone dipping at this angle, and is itself underlaid by another sandstone having the same dip. In other words, the last trap on the eastern side of Keweenaw Point is a thin flow of only some two feet in thickness, at this locality, and is interbedded between sandstones which immediately above and below it have the same dip that it has. As the river is followed downwards the dip gradually declines in steepness, although still dipping northwest. The last dip measured was N. 45° W. 5°. The conglomerate and sandstone below the first basaltic flow, i. e. that nearest to Torch Lake, has apparently been acted upon by hot waters. The sandstone has been leached, its feldspathic constituents largely changed into clay, and the pebbles are greatly altered and kaolinized. The constitution of the sandstone and conglomerate appears to have been originally the same as that of the bands interlaminated with the trap, except so far as they are modified by the detritus of the latter. In many places this hot-water action has bleached the sandstone and leached out of it all the argillaceous material, leaving it a nearly pure siliceous sandstone (518). This has also converted some of the finer beds into a fine-grained, highly argillaceous sandstone or arenaceous clay, these beds having probably arrested the progress of much of the argillaceous material (519, 520). This water action would certainly account for the absence of fossiliferous remains in the sandstone exposed to its effects. Considerable mica in fine scales was seen in the argillaceous bands. Specimens of the various pebbles were taken from the conglomerate (513, 514, 515, 516, 517). No. 517 is a grayish and reddish-brown granitoid-looking rock, and under the lens is apparently composed of feldspar holding quartz grains. Microscopically it is seen to be a crystalline aggregate of decomposed feldspar and hornblende, holding much secondary quartz. The quartz is arranged in the feldspar in the *graphic* or eozoön form, which makes the decomposed feldspar a most beautiful object in polarized light. The contrast between the brilliantly polarizing quartz and the feebly polarizing, kaolinized feldspar substance is thus strongly brought out. The quartz appears to have been deposited from the decomposed feldspar itself, which breaks up into silica and the kaolin-like material. The quartz contains full fluid cavities, those with bubbles, and vapor cavities. The hornblende is in the usual reddish-brown decomposed masses. Some magnetite was seen. This rock is most probably a decomposed old trachyte, although it would doubtless be regarded as a granite porphyry by most lithologists. No. 515 is a similar but more feldspathic rock. No. 513 is similar to No. 527, and Nos. 514 and 516 are like No. 524. Many pebbles or lenticular masses of clay were seen, that are apparently decomposed pebbles of the conglomerate.

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* Proc. Bost. Soc. Nat. Hist., XI. 244-246.

† Geol. of Mich., Part II. p. 3.

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* Senate Docs., 1st Sess. 31st Cong., 1849-'50, III. 782; Executive Docs., 1st Sess. 31st Cong., 1849-50, IX. Doc. 69, p. 67.

In the sandstone quarry at the head of the *incline* on the Hecla and Torch Lake Railroad, the sandstone layers have been regarded as being nearly horizontal. The joint planes that form the floors of the quarry are nearly so, having only a slight dip to the northwest; but these joint planes cannot be the bedding planes, for we find on close examination that numerous layers of coarser material, pebbles, clay masses, etc. occur in the rock. These layers extend for long distances through the sandstone, and are always parallel, having the same dip, which is N. 45° W. 15°. These of course, from their character and regularity, must mark the old planes of bedding, while the generally supposed bedding planes are secondary joint planes cutting the bedding planes at a small angle. This sandstone (456, 457, 458, 459, 461, 462, 463, 464) has been leached and acted upon by water the same as that below the Douglass Houghton Falls, and its feldspathic material converted into clay or entirely removed. Part of the materials composing the sandstone, especially in the coarser portions, are similar to those in the sandstone at Marquette. The quartz grains are partly water-worn, but a large proportion are seen to be short crystals formed of the hexagonal prism, terminated on both ends by the pyramid, or the usual form found in the acidic porphyritic rocks. It appears, then, as the facets of these crystals are comparatively unworn, that they were derived from the destruction or decomposition of trachytic and rhyolitic rocks (granitic and quartz porphyries), the feldspathic material having been removed since by water, leaving a quartzose sandstone. It is a question worthy of examination whether any other sandstones have been formed from acidic volcanic material, from which nearly all the other parts of the rock have been removed by percolating waters; especially as other sandstones have been said to be composed of quartz crystals.

As the sedimentary rocks are more and more studied, the evidence comes on every side that, like this sandstone, while their formation may have taken as long as is generally supposed, they may have been deposited very rapidly, some being composed of old volcanic scoria, ashes, and mud. In very many other cases the supposed sedimentary rocks are really volcanic flows or intrusive masses. In the sandstone just described the same masses of clay (460) occur as on the Douglass Houghton River, and they may arise here, as there, from the decomposition of the enclosed feldspathic or argillite pebbles. Another solution of the question of the origin of some of these would be the filling in of cavities formed by the removal of some other material, by the argillaceous material brought from above. This is suggested by the finding of stalactites of the sandstone (464) extending down into the clay. At the spring just above the quarry the sandstone (521) is red spotted with white, and dips N. 45° W. 14°.

The relations of the traps to the interbedded sandstones and conglomerates have been given before. The trap has, when covered by the sandstone, been worn by water, and the latter rock deposited upon it. The sandstone, in its lower portion, holds to a greater or less extent the *débris* of the underlying trap. Should we apply then rigorously the logic of the Michigan and Wisconsin geologists, we should make a distinct geological age every time a bed of sandstone or conglomerate was formed over any of the trappean flows. Their method of reasoning would prove that the Keweenaw series is made up of some forty to sixty different geological ages, every one as distinct from the age of the rocks underlying it, as they would make the Potsdam sandstone distinct from the Keweenawan.

Besides the melaphyr pebbles and detritus, the conglomerates are composed of similar pebbles to those found in the conglomerate of the eastern side. No. 552, from the Hecla mine, has a dark reddish-brown groundmass, holding white and pinkish feldspars and quartz. In the thin section it is seen to be an old rhyolite, and to have flowed as a lava, for it possesses the contorted, twisted, fluidal structure seen in so many of the rhyolites from the Cordilleras, with which it can be perfectly parallelized, except so far as the alteration has removed some of its original characters. It shows the same twisting and interweaving of the brownish-colored glassy material that they do; its quartzes are fissured and rounded, and penetrated by the base the same as they are in modern rhyolites; and in like manner they are seen to be of prior origin to the consolidation of the lava. The quartz here, as in the rhyolites, plays the same part that olivine does in the basalts and hornblende in the andesites. It is a foreign ingredient, of prior origin to the lava, and has not crystallized out of it.* The quartz contains stone, vapor, and fluid inclusions. The majority of the fluid and vapor (empty) cavities are arranged along fissures, as if they had been formed by hot waters depositing silica in fissures. The feldspar is thoroughly kaolinized, and, like the quartz, is frequently in rounded and broken pieces, which show that it was formed prior to the consolidation of the lava. Considerable secondary quartz occurs in the groundmass, but the base affects polarized light but little, if at all.

It is intended to figure this section in connection with some of the rhyolites of the Cordilleras, for if ever a section showed conclusive proof that the view, that volcanic action did not commence until the Tertiary epoch, is fallacious, this is one. No. 553, from the same locality, has a similar, but lighter brown and less abundant groundmass. This holds numerous yellowish-red and clay-colored feldspars, as well as much quartz. This rock, like the preceding, is an old rhyolite (quartz porphyry). The base is an olive-brown, felty mass, holding opacite grains, quartz, feldspar, and decomposed black hornblende. The characters of the quartz and feldspar are like those in the preceding rock. On the edges and in the cleavage planes of the feldspar, copper has been deposited in both of these rocks. No. 554, from the same locality, is a grayish-red, granitoid rock. In the thin section this is seen to be like the more granitoid trachyte pebbles found towards Torch Lake, and described before. This contains much secondary quartz, and a little that appears to be primary. The feldspars are decomposed, and the quartz is so arranged in them that they show the *graphic* characters. The rock holds numerous rows of ferrite globules, which rows are arranged in a radiate form, giving to the slide a spherulitic appearance. A little of the feldspar is seen to be triclinic. No. 562 is a pretty brown rhyolite (felsite) with a very compact groundmass, holding some minute feldspars. This was taken from the conglomerate of the Osceola mine. The feldspars are seen to be largely triclinic, while the groundmass is a brownish devitrified aggregate of secondary quartz, feldspar, and ferrite. The finer portions of the Calumet conglomerate are seen microscopically to be composed of the rhyolitic and trachytic detritus, the former predominating. In one of the enclosed fragments, quartz was seen containing several of the double pyramidal inclusions so common in the quartz of modern rhyolites.

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* Bull. Mus. Comp. Zoölogy, V. 277-282.

On the Mineral Point Railroad, about three fourths of a mile from Hancock, the melaphyrs were seen to be interbedded with a number of conglomerates. Certain pebbles intended to represent the different varieties were collected. No. 419 is a very compact, fine-grained, reddish-brown rhyolitic rock (felsite). In the thin section it shows a compact groundmass, made up of the devitrification products: quartz, feldspar, and ferrite. No. 420 has a reddish-brown groundmass, holding reddish feldspars and black hornblendes. The feldspar is seen in the thin section to be much decomposed, and part holds quartz in the *graphic* form in it. Some retains traces of its triclinic character, but all has the same hematite alteration product that is common in orthoclase. The hornblende crystals of this old trachyte are changed to ferrite and viridite. Besides the quartz, ferrite, and viridite, as another alteration product epidote occurs. This mineral is quite abundant. Magnetite and some apatite were seen. No. 421 has a very compact, reddish-brown felsitic groundmass, holding feldspar crystals. This old trachyte (feldspar porphyry, or felsite), in the thin section, is seen to have a reddish-brown groundmass, composed of alteration quartz, feldspar, and ferrite. The porphyritically enclosed feldspars are largely plagioclase. No. 422 is another trachyte (felsite porphyry), containing numerous reddish and greenish-gray feldspar crystals, held in a dark, reddish-brown groundmass. Microscopically the feldspars and groundmass are seen to be greatly decomposed and kaolinized. Viridite, epidote, opacite, and quartz occur as alteration products. This rock is closely allied to the andesites.

No. 423 is a very fine-grained reddish granite, composed of feldspar, quartz, hornblende, and biotite. Considerable alteration quartz, ferrite, and opacite were seen. The feldspars are much altered. The quartz contains fluid, vapor, and stone cavities, also numerous trichites.

No. 424 is a brick-red granitoid trachyte (granite porphyry). The feldspar is much decomposed, and has the alteration quartz arranged in the *graphic* form. The rock shows through its alteration a somewhat spherulitic structure. This arises from the radiating arrangement of the alteration products in the groundmass. The sandstone found associated with the conglomerates is made up of the fine detritus of these trachytic and rhyolitic rocks, mixed to a greater or less extent with the basaltic material.

The sandstone and conglomerate west of the traps were studied in several places, especially at Copper Falls, west of Houghton, and northwest of Hancock. At the latter locality, marked *slates* on the map of the Portage Lake district, by A. R. Marvine and L. G. Emerson,* or, in other words, at the bottom of the ravine below the curve, at the end of the heavy grade of the Mineral Range Railroad, they were examined the most thoroughly, as that locality seemed to be the most probable place to find fossils, if any existed in the sandstone. Although our search was unsuccessful, we think it very probable that, if one had the appliances for more extended work, fossils might be found here. The contact of the sandstone with the traps was not seen here. In the parts nearest the latter it is a coarse, reddish-brown sandstone, composed of reddish feldspar, quartz, and basaltic detritus (387, 388, 409). It is composed of the same materials as the sandstone, interbedded with the basalts, although it perhaps has more basaltic detritus than they do. The enclosed pebbles appear to be trachyte (felsite porphyry), of the same character as those found within the trappean district near Hancock (389).

As we recede from the traps, the sandstone becomes finer, or passes into a shale composed of the same materials (390, 391). Lenticular or rounded concretions occur in the shale, which closely resemble pebbles (392). Little spherical concretions of sand, similar to those described by Messrs. Foster and Whitney,† occur here (393, 394). In some of the coarser portions of the sandstone, interstratified with the shale, little fragments and scales of argillite were seen (395). Some of the shale is fine and earthy (398), and in places shows rain-drop impressions (399, 400), ripple-marks (400, 401, 402), and mud-flows (403, 404, 405, 408). About two miles above Hancock the sandstone was formerly quarried, on the shore of the lake. Its dip is N. 30° W. 23°. The dip of the conglomerates nearer Hancock, interstratified with the traps, is 40°. Any inequality of the lava flows or of the shore deposits of sand and pebbles would give rise to a change in the dip of succeeding beds.

West of Houghton, sandstone and conglomerate of the same general character was observed dipping N. 45° W. 30°. It is probable that the Laumontite ("red Zeolitic mineral") which Dr. Rominger describes as occurring here, and also forming the cement of the conglomerates elsewhere,‡ is the red feldspar of the trachytes (felsites). The material of which the western sandstone is composed, and its junction with the trap, all show that it is of the same geological age as the trappean rocks, although younger in point of time.

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* Geol. of Mich., I., Atlas, Plate XIV. *a*.

† Executive Docs., 1st Sess. 31st Cong., 1849–50, IX., Doc., 69, p. 112.

‡ Geol. of Mich., I., Part III. pp. 97, 98.

The sandstones and conglomerates are evidently beach-worn, and are simple shore deposits. Whence the trachytic and rhyolitic material came, is a subject worthy of future investigation. They were evidently lavas that had been erupted prior to the basaltic flows, and a knowledge of their original position, as well as tracing the different kinds to their present resting-place, would give us considerable knowledge of the physical geography of that old sea. The conglomerates occurring interbedded with the traps would of necessity be more limited and variable than the lava flows themselves, for they could only be deposited upon the part of the lava that lay along the shore line, and even there only in those places where the conditions were favorable to the accumulation and retention of detritus. The amount of conglomerate would in some measure depend upon the length of time elapsing between the basaltic flows; but on account of the local nature of the conglomerates, their absence at any particular spot does not prove the immediate following of the succeeding eruption, or that no conglomerate exists elsewhere between the two lavas.

While we were able to do nothing to prove the geological age of the eastern sandstone, it seems that Dr. Rominger has brought forward evidence conclusively establishing the correctness of Messrs. Foster and Whitney's view, based on its stratigraphical relations, that it was of Potsdam age. We have shown sufficient evidence to prove that in the parts visited by us the eastern sandstone conformably underlies the trap, and that, as held by Messrs. Foster and Whitney, the eastern and western sandstones, and the traps lying between them, are of the same geological age. Whether the idea is correct or not, as held by these gentlemen, that the eastern sandstone at the Bohemian and Porcupine Mountains is younger in order of time of deposition than the traps, and was originally continuous with the western sandstone, we cannot say, having never studied the sandstone in either locality. It is, however, plain that such is not the relation of the eastern sandstone in the vicinity of Torch Lake to either the traps or western sandstone. It is also evident that the volcanic action began gradually the same as it ended, and produced similar alternations of trap and sandstone on both sides of Keweenaw Point.

The Veins and Copper Deposits.

At some time after the sandstones, conglomerates, and traps were laid down, extensive and deep-seated fissures were formed, generally extending, in the district north of Portage Lake, across the beds. These fissures seem to have been formed by powerful movements of different parts of the rocks, causing their cross fracture and dislocation. The movements have been repeated from time to time, causing a rubbing, grinding, breaking, and polishing of the parts adjacent to the fissures, forming numerous slickensides. These movements would not cause irregular and secondary fracturing to any great extent after the main fissures had been formed, in the heavy-bedded diabases or the sandstones; but in the scoriaceous and thin-bedded melaphyrs, the tendency to yield to the pressure was much greater, and the rock adjacent to the fissures was broken up to a considerable extent. During the time of the fracturing, and since, the fissures served as channels for water. In the scoriaceous and easily decomposable melaphyrs the water served by its decomposition of the adjacent rock to widen the fissures, but in the diabases, although their composition was the same, their structure and the absence of much glass prevented the same results occurring. The sandstones and conglomerates, from their being principally composed of trachytic and rhyolitic material, and from their structure, suffered little, compared with the melaphyrs, from vein formation.

In many localities the evidence is strong that the percolating waters were hot; in others, as remarked by Marvine, no sign exists that it was above the temperature of the present day. Water penetrated with greater or less readiness through the traps themselves, causing their decay and alteration, while the substances taken up in solution by it were deposited in the fissures, cells, and other open spaces in the rock. The filling of pre-existing cavities and fissures gave rise to the amygdaloidal structure of the traps and the vein material; the decomposition of the trap, and its replacement of some materials by others, gave rise to the pseudo-amygdaloidal structure. This structure exists not only in the non-scoriaceous or non-cellular portions, but also in the truly scoriaceous or cellular portions.

All or nearly all of the material filling the veins and adjacent traps appears to have been derived from the decomposition of the traps themselves, and not brought in from extraneous sources,— this decomposition being brought about by the medium of the percolating waters, whose course seems, in many cases at least, to have been downwards. The partial decomposition of the fractured portions of the traps and the filling of the interspaces by the vein matter give rise to the great width which the veins sometimes attain, — thirty feet. While the veins in the narrower portions are often filled with pure vein material, in the wider parts they are composed of a breccia of decomposed trap cemented by vein matter. The comby and sheet structure of the veins, the class of minerals enclosed, the decomposition of the associated melaphyr, — in fact, all their characters, — point out that these are true fissure veins filled by segregation.

In the veins the copper is found intimately mixed with the gangue, or in sheets or irregular masses. The copper in the sheet form, as is much of the mass copper of the veins, extends downwards, or has its sides approximately parallel with the walls of the vein. Oftentimes the sheet bifurcates, holding some of the gangue or melaphyr between its parts (818). On cutting the mass copper it is not uncommon to find completely enclosed in it masses of melaphyr, quartz, calcite, or other of the vein materials. The association, structure, and the relations of the copper to the vein material and to the traps, all show that it was deposited in the same way the vein matter and secondary materials in the traps were.

The melaphyrs adjacent to the veins are often impregnated, in the decomposed portions, with copper, as well as the usual secondary deposits. In certain cases it has paid to take out the parts adjacent to the vein, but fallacious have proved and will prove the hopes of continous profitable mining based on these local deposits. Vein mines associated with local deposition of copper in the adjacent traps have been and are now so abundant at Lake Superior that it would be invidious for us to specify any one of them. In the vicinity of Portage Lake the old lava flows themselves are mined. No trace or sign of a true fissure vein exists in most of the beds that are mined in this locality. The mining is confined to work upon unstratified deposits, the same as if some of the more cellular and deeply buried lavas of Vesuvius or Etna were for any reason mined. These melaphyrs have been greatly acted upon by hot waters, which have decomposed them, and deposited the copper in an irregular, "bunchy" manner. On the Isle Royale lode this hot-water action is very strongly marked, the original basalt being now greatly altered, and filled with epidote and quartz, or other minerals (377, 378, 379, 380, 381, 382, 383, 384).

In others the action is not so strongly marked, but more evenly distributed throughout the bed, as for instance the Quincy. All these bed mines have their deposits distributed in a very irregular manner, requiring much dead work as a neccessary concomitant of the way in which the copper was deposited.

Another variety of the bed mining is that known as *ash-bed* mining. As stated before, the ash-bed is a more scoriaceous flow than the generality of the melaphyrs to which it belongs, and has the copper deposited throughout its mass, not rich, but quite uniform, or subject to certain well-marked laws of variation. So far as could be ascertained, the ash-bed shows no sign of hot-water action at Copper Falls, but rather evidence that the copper was deposited from a cold, or, at most, only a warm solution. The rock is but little changed, and retains part of the signs of its fluid state, almost as well marked as they are in some comparatively recent lavas. In other mines in which a transverse fissure vein and a melaphyr (amygdaloid) is mined, the impregnation of the melaphyr with copper seems to be dependent upon its proximity to the vein, being rich near the vein, but growing poorer as it recedes from it. Here the conditions are reversed : the ash-bed is apt to be poorer near the veins than at a distance from them. Where the overlying trap sent down tongues into the ash-bed, the latter became indurated, and consequently but little copper was deposited in it at these places.

The Atlantic mine at Portage Lake is supposed to be on the ash-bed, or a similar formation. This mine was visited, and the rock found to be similar to that of the ash-bed, except much harder. This rock has, like the rock in the other mines at Portage Lake, been subjected to much more intense metamorphic action than the ash-bed at Copper Falls. The copper here, however, is quite evenly distributed, and all of the bed is stoped out and sent to the stamp-mill. So far as could be told by lithological evidence, the Atlantic mine is on the same bed as the Copper Falls mine, or on a bed having the same origin. The action of thermal waters on the former accounts for its present difference from the latter.

The induration of any rock does not apparently depend upon the question of the heat of the water which acts upon it, but upon the deposition of mineral matter in the rock by the water, and on the hardness of the deposited minerals. No mineral matter need be brought in ; the induration requires only that the chemical constituents should reunite into minerals of greater hardness. These alterations are always a passage from unstable to more stable compounds, in the conditions to which the rocks are subjected. Glass is the most unstable form in which any of the rock constituents can be ; but the melaphyrs, from their origin and the conditions to which they were subjected at the time of consolidation, must have possessed a vast amount of glassy material. Hence they were most liable to decomposition and alteration, which might or might not result in induration. At Copper Falls no general induration exists, except, for instance, where quartz has been deposited, but at the Atlantic the induration is general. We have seen, that the action of hot waters on the sandstone at Torch Lake gave rise to the reverse of induration, as its action was that of removal, and not of deposition.

The last form of copper deposit in the district visited by us is that of the conglomerate mines. The beds of conglomerate are composed, as before said, of rhyolitic, trachytic, and basaltic pebbles and detritus. In some of these conglomerates, as the Calumet and Hecla, the cement has been removed, and its place, or the original interspaces, filled with copper. In some cases melaphyr pebbles have been largely removed, and their places filled with copper, giving rise to boulder-like forms (471). These conglomerates, then, are simply old sea-beach deposits, and, like the amygdaloids and ash-beds, are not veins, and cannot properly be so called. They must of necessity partake of the characteristics of their origin, the same as veins do of theirs.

The copper has been found throughout the district underlying heavy beds of trap or a series of smaller ones; in fact, in the parts visited by us, experience has shown that copper in abundance was only found where trap in large amounts overlaid the vein or bed. The copper was found filling, at the Calumet and Hecla mine, the joints of the overlying trap, and extending as a continuous sheet through fissures at right angles to one another. At Copper Falls spikes of copper extend downwards out of the overhanging trap into the ash-bed. These are generally large at the upper end, and pointed at the lower. Like them are the secondary depositions of calcite, in this trap, in long, spike-like forms, that here and elsewhere have been taken for fossils. These features prove that the copper came from above downwards, and that it was deposited after the jointing of the trap. In fact, the evidence is strong that all the alteration and fissuring of the rocks, and the deposition of the copper and associated minerals, took place after the western sandstone had been deposited. The above facts indicate that the copper was derived from finely disseminated copper distributed throughout the lava, as modern lavas have been known to contain it. If it was derived from the sandstone, as advocated by Bauerman and later by Pumpelly, it should be found in connection with the sandstone; but such is not the case. The farther from the sandstone, and the nearer the heavy beds of trap, the larger have been the deposits of copper, e. g. Cliff, Central, and Calumet and Hecla. The conglomerate of this last mine was not the home of the copper; it is simply the place where it has been deposited by secondary agencies. The statement now kept up for some thirty years in Dr. Dana's works, that the copper is chiefly found at the junction of the sandstone and trap, is a good illustration of how an error once in a text-book cannot be eradicated.

Conclusions.

The general geological structure of the region visited by us is, then, in general, as follows. Beginning on the southeastern side of Keweenaw Point we find a sandstone and conglomerate overlaid by melaphyr. This melaphyr is again overlaid by sandstones and conglomerates; principally the latter. The alternations of melaphyr, diabase, sandstone, and conglomerate, with the melaphyr and diabase largely predominating, continue across the centre of the Point, forming its backbone. As the northwestern side is approached, the sandstones and conglomerates increase, while the melaphyr and diabase diminish, until a purely sandstone formation is reached.

All these rocks taken together make one geological formation, and have been laid down successively one upon the other, in order, going from the east towards the west. These rocks are known to form the same series by their conformably overlying one another. These traps are old lava flows, spread out over the then existing surface along a shore line. They have flowed the same as modern basaltic lavas do under like conditions, and retain the same characters, except so far as they have been modified by the agencies to which they have been subjected since their outflow. They are known to be old lava flows by their baking and indurating the immediately underlying rock, by their sending dikes and tongues down into this rock, by their scoriaceous character on the upper surface, by their signs of having flowed, and by their microscopic characters. That they were laid down before the overlying rock is shown by their producing no effect upon it; by their presenting on the upper surface only the irregularities and rounded knobs that such surfaces are known to have, especially when they have been worn; by rounded pebbles and boulders of the underlying traps, being enclosed in the overlying conglomerates; by the absence of fragments of the overlying rock in the underlying one; and by the absence of any characters showing intrusion of the traps between the different beds. The extent of these old lava flows, except as seen along their upturned edges, is not known, for they have been followed by mining along their incline some 2,100 feet only. Judging from their length, their width must be considerable. In thickness they partake of the same irregularities which any similar flow has. Locally the thinner and more scoriaceous flows are known as "amygdaloids," the thicker and more compact ones as "traps," and the thickest one on the western side as "greenstone." The difference between these several forms of old basalt seems to be occasioned only by the variable amount of lava erupted at different times, and the slightly different conditions to which the flows were subjected.

Most of these old basalts are directly covered by succeeding flows, following after greater or lesser intervals of time; but part, as remarked above, are covered by conglomerates and sandstones. These conglomerates and sandstones show, by the rounded and water-worn character of their constituent pebbles and grains, that they are beach deposits. The surface of the underlying basalt is smoothed as by water action. The overlying conglomerate is made up at its base of basaltic mud and pebbles, derived from the underlying rock, and mixed with the felsitic mud and pebbles of which the conglomerates are chiefly composed. The trappean mud and pebbles diminish, or are entirely wanting, as we recede from the underlying trap. That the basalt is a metamorphosed sandstone, as is often contended by mining men, is disproved by the facts given above, and by the further facts, that there is no gradual, but an abrupt, passage between the two; that all fragments of sandstone caught up by the trap are baked and indurated by the heat, but show no signs of passage; and, lastly, that it would demand the conversion of an acidic rock into a basic one.

From the conditions given above it would not be surprising to find the lava flows locally limited at any point, and partially or even entirely denuded, and replaced, in part or as a whole, by conglomerates and sandstones. This would depend, of course, upon the position of the shore line, and upon the conditions to which the basalt was subjected during the time of its flow, or since. A still greater variability is to be looked for in the conglomerates and sandstones. All these conditions are to be taken into consideration in the mining of these old lava flows and their associated conglomerates.

In the Portage Lake and Keweenaw Point districts there are mined at present four forms of deposits: —

1. Melaphyrs of an amygdaloidal character, known as "amygdaloid" mines, which have been subjected to hot-water action, and whose deposits of copper are "bunchy" and irregular. These are in no sense veins or lodes, and the Quincy and the Shelden and Columbian mines are good examples.

2. Ash-bed mines, which are truly melaphyr or "amygdaloid" ones, but the melaphyr is of a more scoriaceous character, as was pointed out above, of which the Copper Falls (in part) and the Atlantic mines are examples.

3. The conglomerate or true bed mines, like the Calumet and Hecla.

4. The true fissure vein mines, like the Central, Phœnix, and Copper Falls (in part).

The first two forms should be classed as one.

It is an established rule that a mineral vein, in passing from one bed of rock into another of a different nature, is apt to vary in width and contents. Such variations in dimensions and gangue have been repeatedly found in this district, as the different beds are comparatively narrow. As might be expected, the variation is not so strongly marked in the different melaphyrs, since they are all rocks of the same composition and origin, differing only in texture, thickness, and crystallization. One and the same vein may then vary in width, from a mere seam to thirty or more feet, as is the case with the "Owl Creek Vein," as mined at Copper Falls. Under these conditions one cannot judge with any certainty, from the appearance of the vein at one point, what will be its width or character at another. The decision must be based on probabilities only. In places the fissure may be filled with true vein material, while in other parts, especially in the wider portions, it may be filled with fragments of the melaphyr, cemented together by vein matter. The width of the vein will depend largely upon the readiness with which the country rock yielded to the crushing and grinding force, and to the action of the percolating waters. We should expect, then, the veins to be mere nominal fissures in the sandstones, conglomerates, and heavy "greenstone," but to be more or less well marked in the "amygdaloids" and "traps."

The filling of the veins and of the cavities in the melaphyrs, it appears, was accomplished by the same agencies. The amygdaloidal structure of the melaphyr is owing to the filling with mineral matter, with greater or less completeness, gas cavities formed at the time of the lava flow. Besides the true amygdaloidal structure, there are numerous cases of pseudo-amygdaloidal structure. This last arises from the alteration of the formerly solid parts of the melaphyr, and is to be found not only in the compact portions (lower) of the rock, but also in the scoriaceous parts (upper). These amygdules and pseudo-amygdules are composed of quartz, calcite, epidote, prehnite, laumontite, analcite, apophyllite, datolite, chlorite, delessite, etc., etc. The constituents of these minerals were derived from the decomposition of the melaphyr, and deposited through the agency of the percolating waters. The vein materials are the same as those of the amygdules, and they are of like derivation and deposition. The copper is found forming a constituent part of the amygdules in many places, as well as of the vein-stone, and it would seem to have been deposited in a like manner. Until we know more about the occurrence of the copper, all theories regarding its origin should be held with a loose grasp, and dropped as the facts developed may require thereafter. It is held by some that the copper was derived from solutions of the metal in sea-water, precipitated by decaying organic matter, and accumulated in the sandstones, shales, and conglomerates of the series. It was then taken up by the percolating waters, and deposited in the places in which it is now found. A second view is that the copper was originally finely disseminated through the lava at the time of its outflow, and has since been locally concentrated by percolating waters in the amygdules, veins, and conglomerate beds. The writer inclines to the latter view, believing that this theory is more in accordance with the facts observed by him than the former one. The final concentration and precipitation seem to be connected in some way with the oxides of iron, which are abundant in the melaphyr and in the detritus of it and of the felsite pebbles, which form the principal portion of the conglomerate. The copper seems to have needed for its deposition some of the following conditions: rocks that were porous and cellular; those whose parts were easily removed by the percolating waters, as the mud forming the cementing material of the conglomerates; the open spaces of veins and fissures; and rocks acted upon by hot waters. The copper, when not distributed through the whole bed, is found principally in the upper portion. Whatever may be our views respecting the sources of the copper, it is evident that it was deposited by aqueous agencies, and that the general course of the solution was downwards. The best vein-stones, so far as observed, are datolite, prehnite, and calcite. Laumontite does not seem to have much mass copper associated with it. While large masses of copper were seen at the Central mine associated with calcite, a similar association is rarely found in the Owl Creek vein at Copper Falls. The best vein-stone there has been datolite. The prehnite here seems in depth to yield to datolite.

The theories of the igneous origin of the veins, and of the igneous deposition of the copper in them, have been so ably refuted in the various papers referred to here that it is unnecessary to discuss them; but owing to the great weight of Professor Dana's name, we cannot pass over his theory without saying that the supposed facts on which it is based do not exist in the Copper district, he having raised the superstructure on the errors of Messrs. Houghton and Jackson, never having visited the region himself.

As in the Iron district, so in the Copper district, the writings of Messrs. Foster and Whitney remain the best and most accurate exponents, as they were the first of value, of the geology of the country, and of the ore deposits studied by us, so far as they were known at that time. All work since, so far as it stands the test of examination, sustains their views and establishes the accuracy of their observations, except in a few particulars. Mr. A. R. Marvine's work stands next in order of value and geological ability shown.

Professor Pumpelly deserves all credit for his microscopic examinations of the old basaltic rocks of the district, and for the extent and thoroughness with which he has applied and carried out the investigations and theories of Messrs. Whitney, Müller, and Bauerman, in his "Paragenesis and Derivation of Copper and its Associates on Keweenaw Point"; but his stratigraphical work was not worthy of the name, and served only to obscure the true relations of the rocks. The volcanic origin of the rocks was proved by Marvine five years before, by Foster and Whitney twenty-eight years before, and announced by Hubbard thirty-two years before Pumpelly accepted it.

Our work proves that the Keweenawan system has no foundation except in insufficient observation and the application of stratigraphical methods and assumptions that will not bear examination. The difficulty here, as in the Iron district, has been in the methods, and in the assumption that certain observations proved that which they did not.

I desire to extend my thanks for favors received while in the Iron and Copper districts to Charles E. Wright, M. E., State Commissioner of Mineral Statistics; Per Larsen, M. E. of the Jackson mine; Agents C. H. Hall, of the Lake Superior mine, William Sedgwick, of the Barnum, D. H. Bacon, of the McComber; Capts. James Pascoe, of the Champion, and Peter Pascoe, of the Republic; also to Mr. David Morgan, President of the Republic Iron Company; to Captain Cliff, and L. G. Emerson, M. E.

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Cambridge, Mass., May 18th, 1880.

APPENDIX.

List of Papers and Works relating to the Geology, Mineralogy, and Physical Geography of Lake Superior.

The writer does not claim that this list contains all that has been written on these subjects relating to Lake Superior, for it is simply the outgrowth of a desire, arising after part of the body of this paper was written, to save others the trouble of doing over again the work that he had already done. It is not intended as a *bibliography* in the approved modern sense, but simply to serve as a stepping-stone to those who may hereafter desire to take up the study of this most interesting region. Papers and works, which from their titles appear to belong to different departments or to other localities, have been given, when matter relating to these subjects or this region, as the case may be, has been found in them. All papers given here that the writer has not seen are marked with an asterisk (*).

In the preceding text, in quoting from the various authors referred to, the intention has been to make the spelling, punctuation, and italics identical with the originals, which accounts for certain peculiarities that the reader will observe.

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The Terraces and Ancient River Bars, Drift, Boulders, and Polished Surfaces of Lake Superior. Proc. Am. Assoc. Adv. Sci., 1848, i. 68-70.

On the Origin of the Actual Outlines of Lake Superior. Proc. Am. Assoc. Adv. Sci., 1848, i. 79.

Remarks upon the Unconformability of the Palæozoic Formations of the United States. Proc. Am. Assoc. Adv. Sci., 1851, vi. 254.

On Marcou's "Geology of North America." Am. Jour. Sci., 1859, (2,) xxvii. 134-137.

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Akermann, H. W.

Die Kupferführenden Schichten am Lake Superior. Sitzungs-Berichte der naturwissenschaftlichen Gesellschaft Isis in Dresden, 1875, pp. 101 – 105.

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Andrews, Israel D.

On the Trade and Commerce of the British North American Colonies, and upon the Trade of the Great Lakes and Rivers. Sen. Docs., 1st Sess. 32d Cong., 1851 – 52, xi., No. 112, 906 pp. Contains a report by C. T. Jackson.

Anonymous.

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The Copper Mines of Lake Superior. Hunt's Merch. Mag., 1846, xiv. 439 – 443.

Ancient Mining on Lake Superior. Hunt's Merch. Mag., 1848, xix. 663.

Elevation of an Island in Lake Superior. Ann. of Sci. Discov., 1851, 255.

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Great Mass of Native Copper. Min. and Smelt. Mag., 1864, vi. 25, 26; Am. Jour. Sci., 1864, (2,) xxxvii. 431.

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Barnes, George O.

See Charles T. Jackson.

Bartlit, William, *and* David Tod.

Mineral Regions of Lake Superior. Senate Docs., 1st Sess. 29th Cong., 1845 – 46, iv., No. 160, pp. 20 – 25.

Bayfield, H. W.

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Beaumont, Elie de.

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Report on the Country between Lake Superior and Lake Winipeg. Geol. Surv. of Canada, Rep. of Prog., Montreal, 1872 - 73, pp. 87 - 111.

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Blandy, John F.

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Stamp Mills of Lake Superior. Trans. Am. Inst. Min. Eng., 1874, ii 208 - 215.

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Bristol, T. W.

See Jacob Houghton, Jr.

Brooks, T. B.

Geological Survey of Michigan, with Maps, 1869 - 1873, i.; Part I., Iron-bearing Rocks, 319 pp.; Part II., Copper-bearing Rocks, R. Pumpelly and A. R. Marvine, 143 pp.; Part III., Palæozoic Rocks, Charles Rominger, 105 pp; ii. 298 pp., contains papers by Messrs. Brooks, Julien, Wright, Jenney, and Tuttle.

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Callender, John A.

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Calvert, John.

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PLATE I.

FIGURE 1 (page 30) represents the contact of the jasper and ore on the left hand with the schist on the right. This section shows the relations of the banding of the jasper to the line of junction. Lake Superior Mine, Ishpeming.

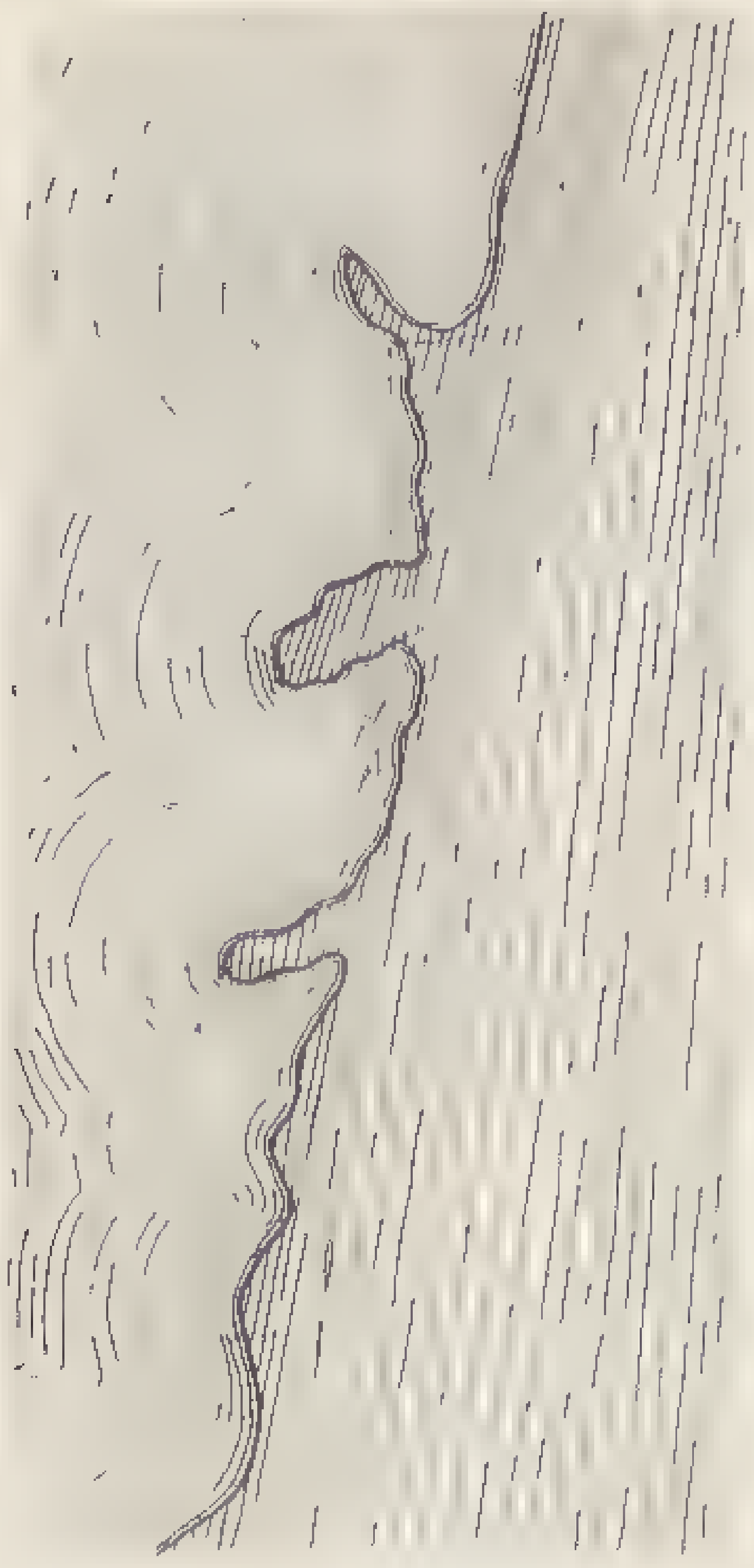
FIGURE 2 (page 30) represents in plan the projection of the banded jasper on the left into the schist on the right, the banding running parallel to the walls. Lake Superior Mine, Ishpeming.

FIGURE 3 (page 30) represents in section a dike of very fair hematite ore, extending across the lamination of the schist. Lake Superior Mine, Ishpeming.

FIGURE 4 (page 31) is a section showing the relations of the branching dikes of hematite to the schist. Cleveland Mine, Ishpeming.

FIGURE 5 (page 31) shows in section the relation of the jasper and ore to the underlying schist. Jackson Mine, Negaunee.

FIGURE 6 (page 31) shows in section the relations of the hematite to the schist. The hematite projects in a large knob-like mass up into the schist, and is connected with the main body of ore below. Jackson Mine, Negaunee.



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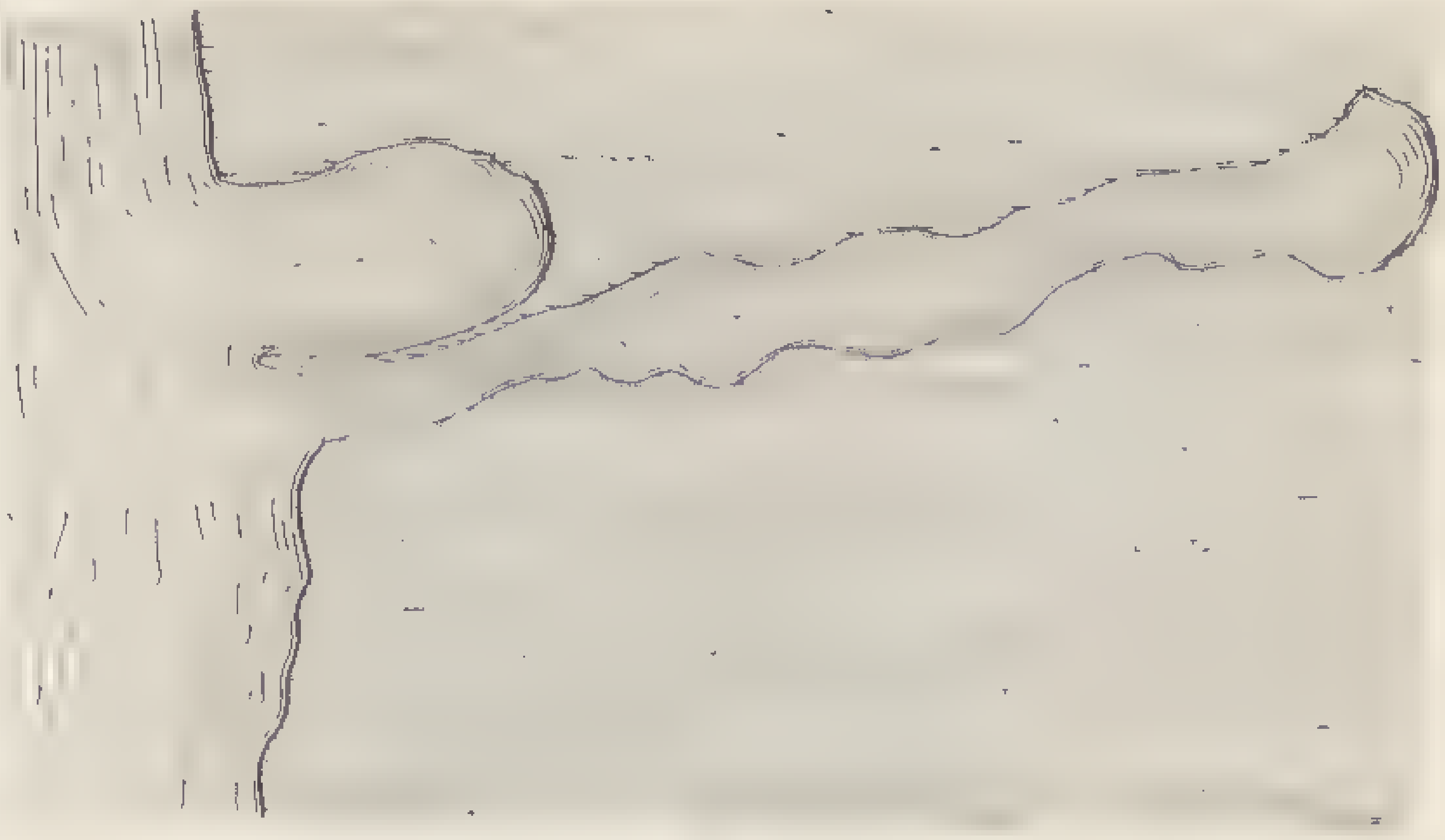

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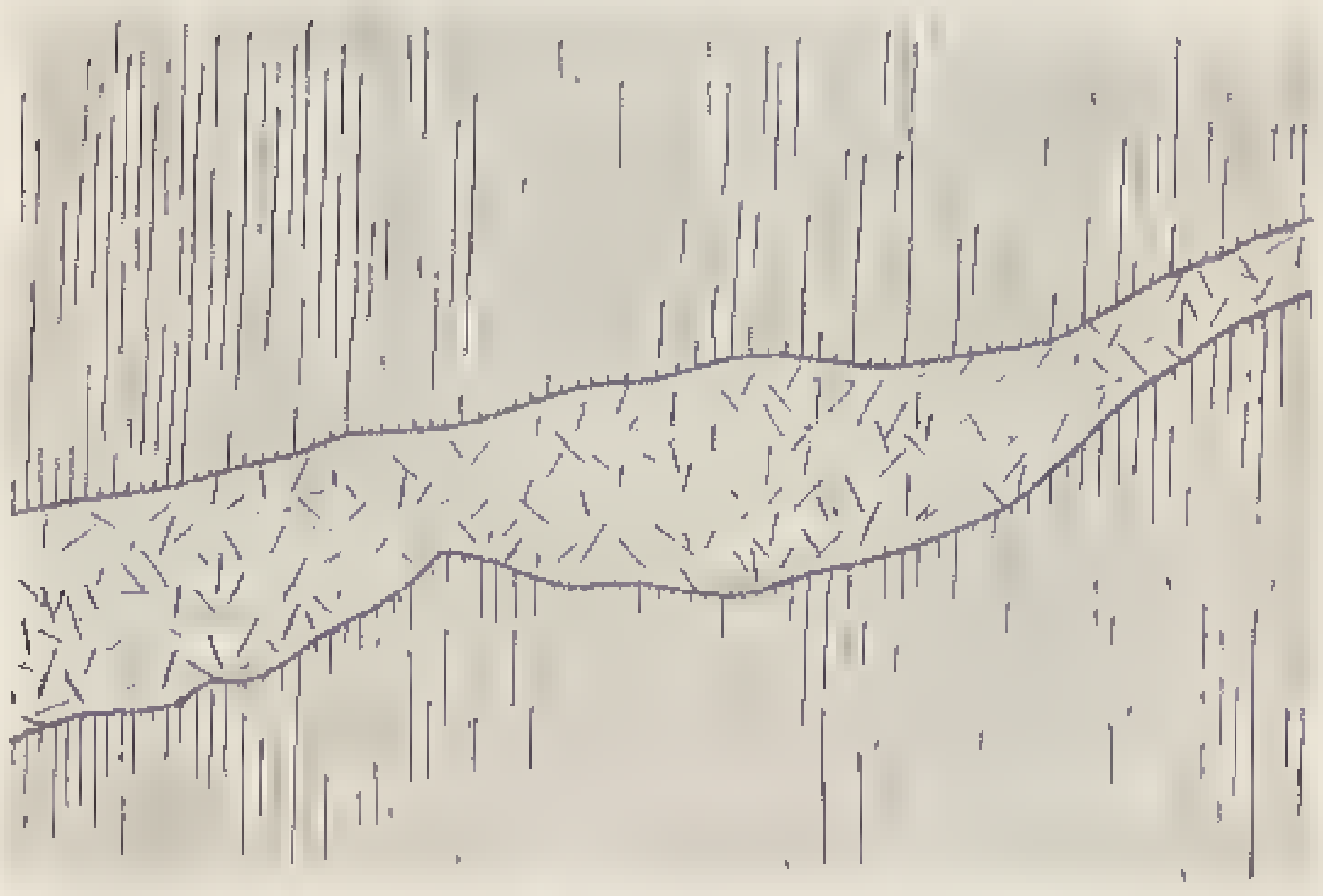

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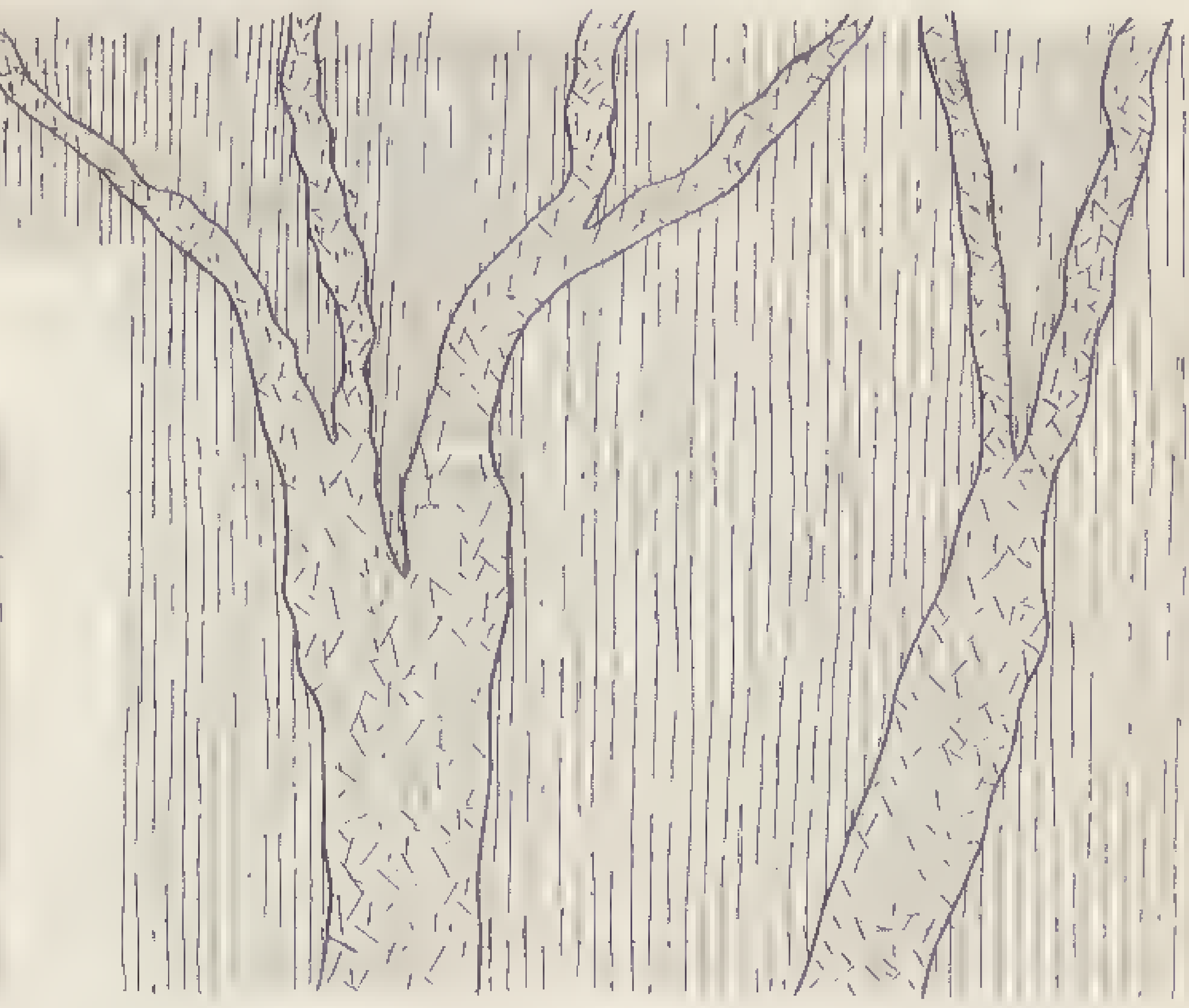

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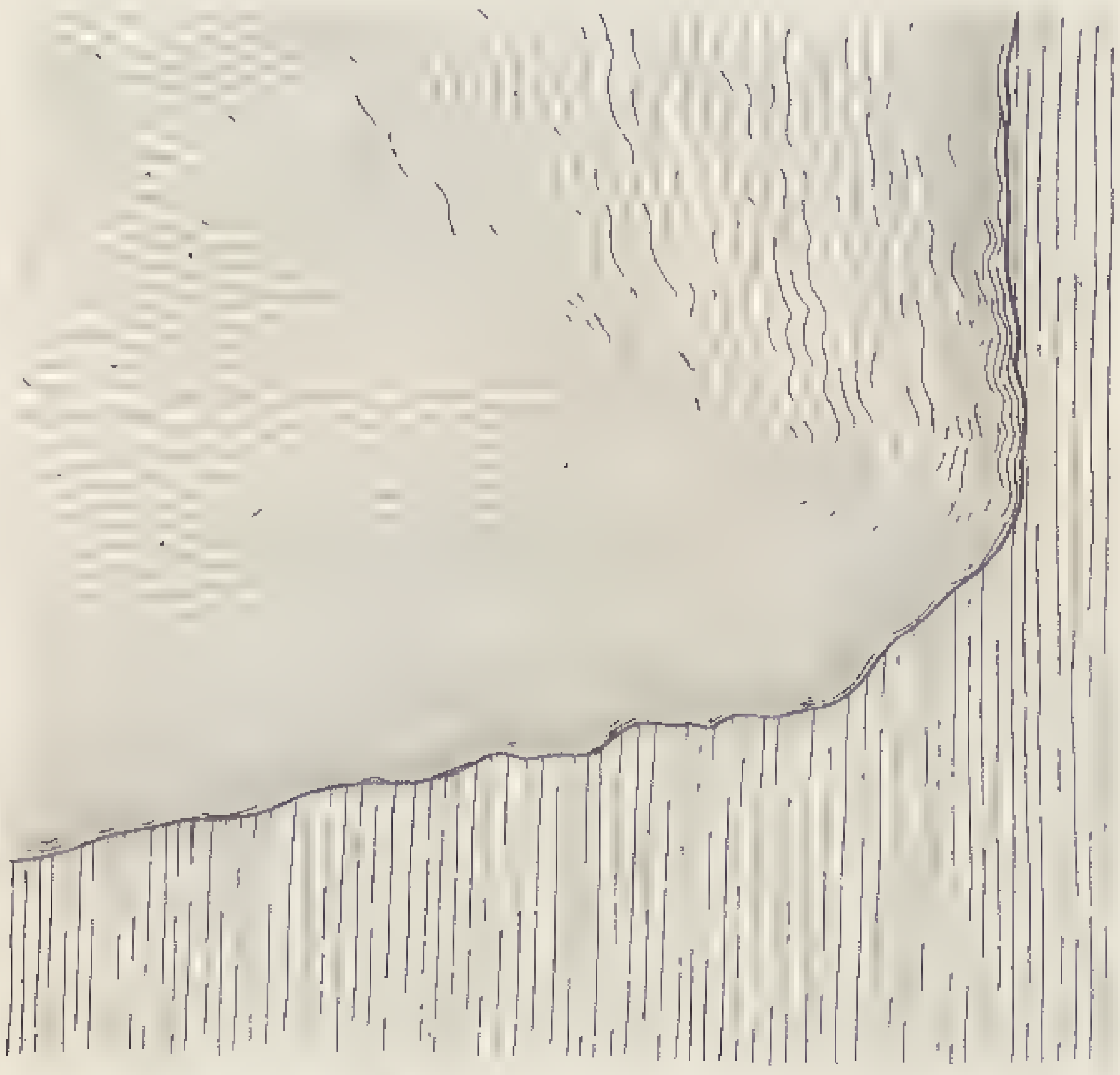

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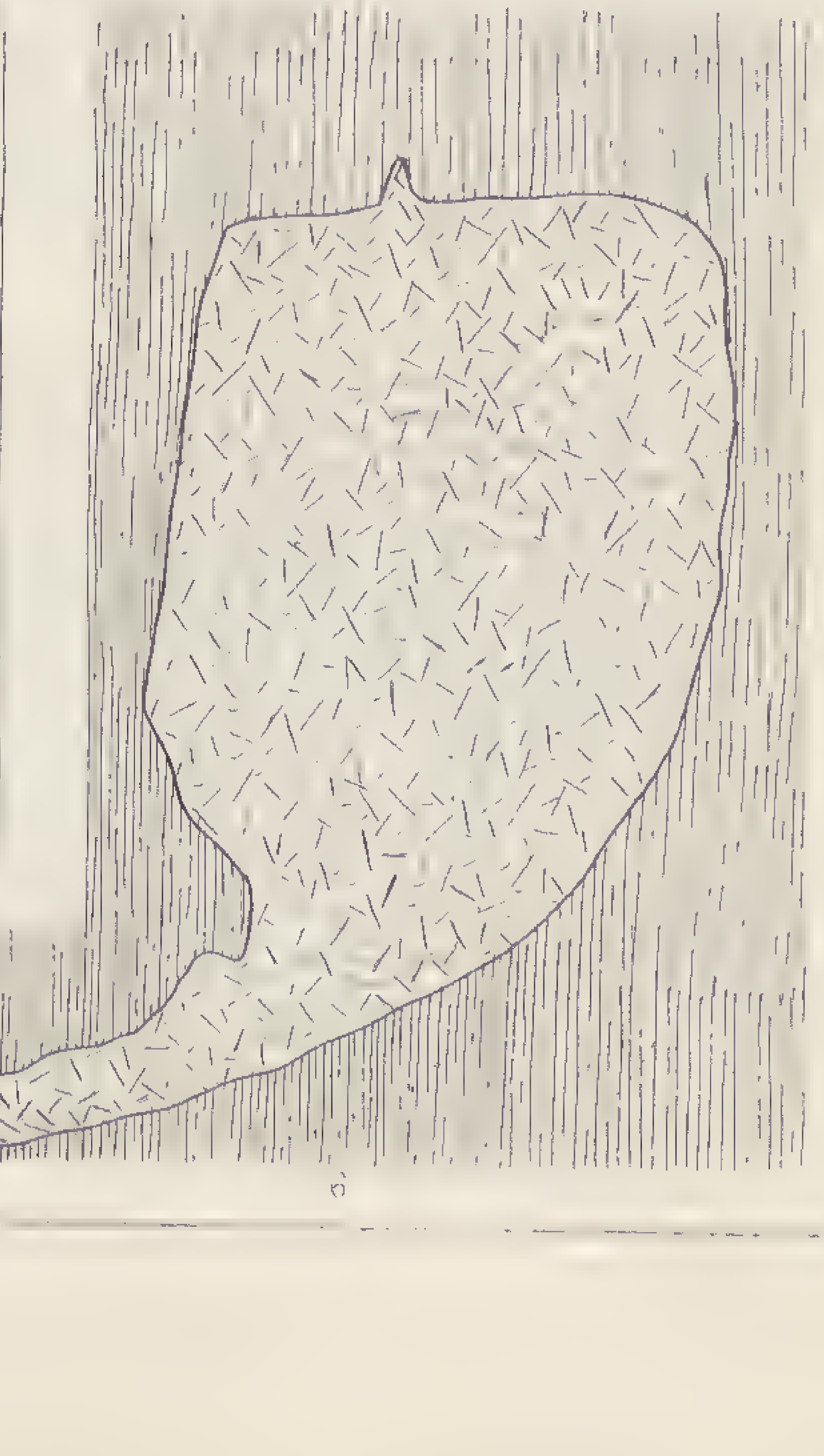

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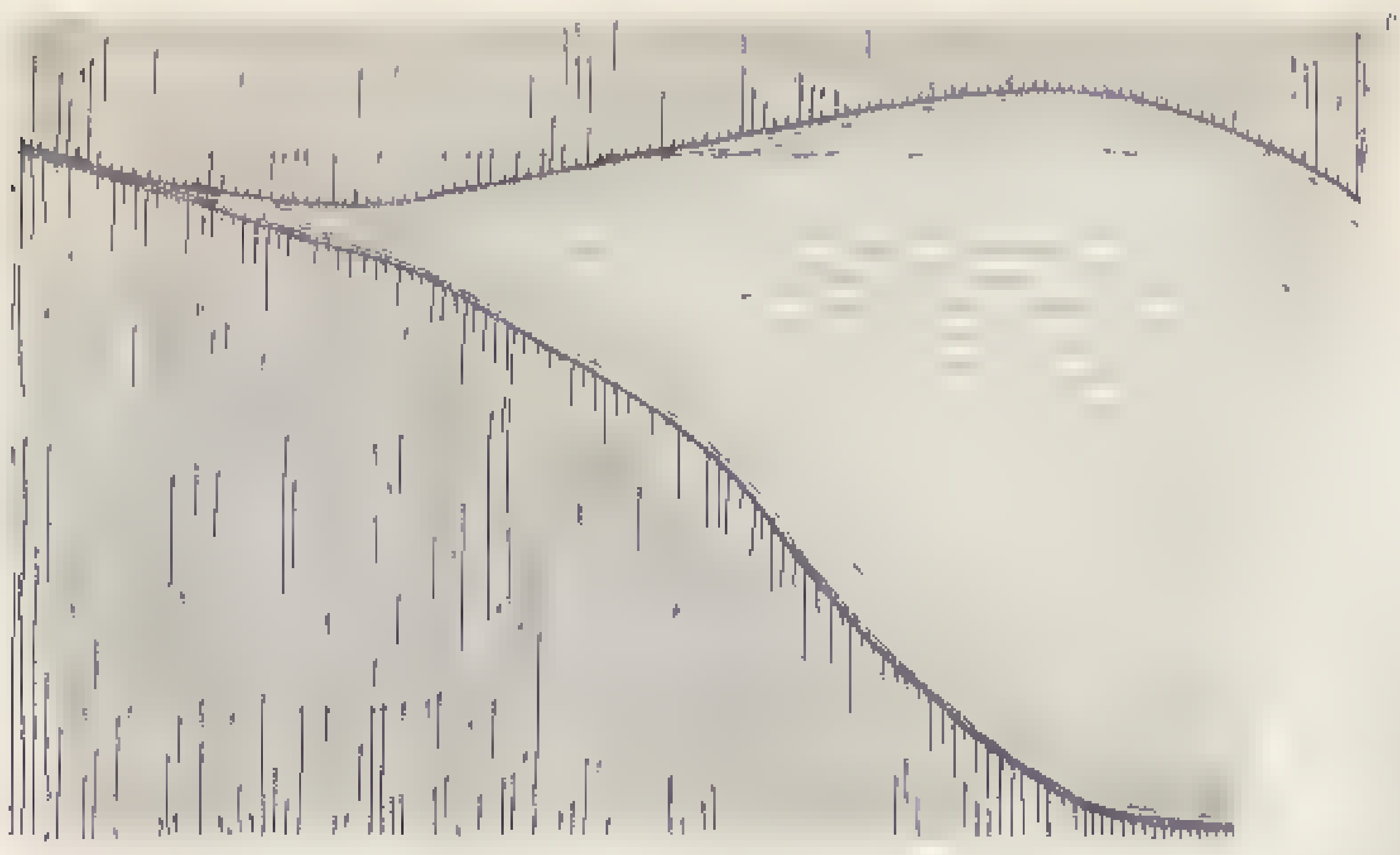
PLATE II.

FIGURE 7 (page 31) represents a section of a dike of iron ore extending across the lamination of the schist. Jackson Mine, Negaunee.

FIGURE 8 (pages 31, 32) represents in section the relations of a decomposed hematite ("soft hematite") to the schist. In this case the curvature and dislocation of the schist by the upthrust of the ore is well shown, as represented along the curve *b*, *c*. Of our own knowledge we cannot state that the part *a* belongs to the hematite on the right, as represented. Jackson Mine, Negaunee.

FIGURE 9 (page 32) shows a section of jasper and ore intruding in a wedge-shaped mass obliquely through the schist. Jackson Mine, Negaunee.

FIGURE 11 (page 32) represents in section the intrusion of ore in a dike of varying dimensions between and across the laminæ of the schist, bending them in different directions, as shown to a certain extent in the figure. Jackson Mine, Negaunee.



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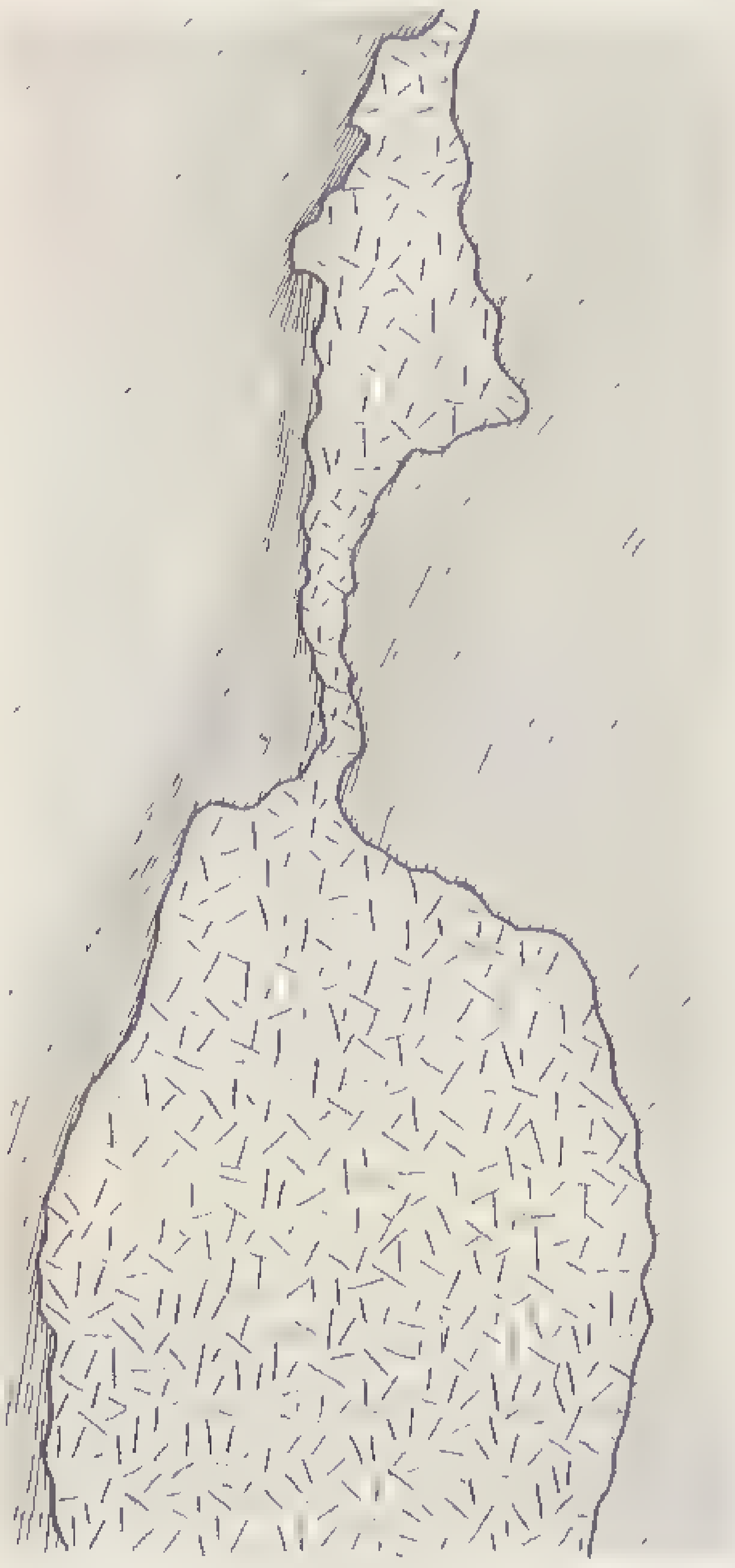

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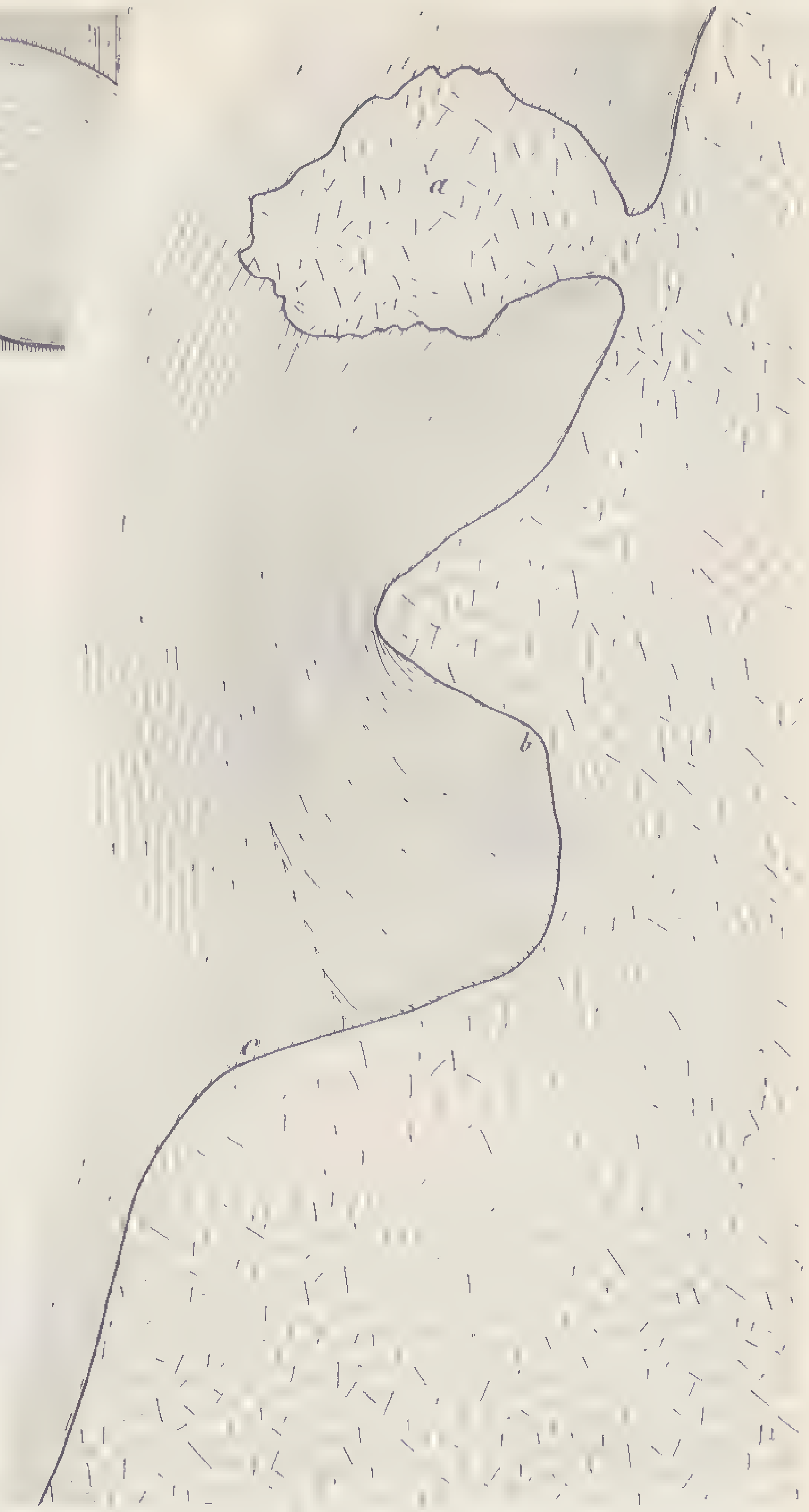

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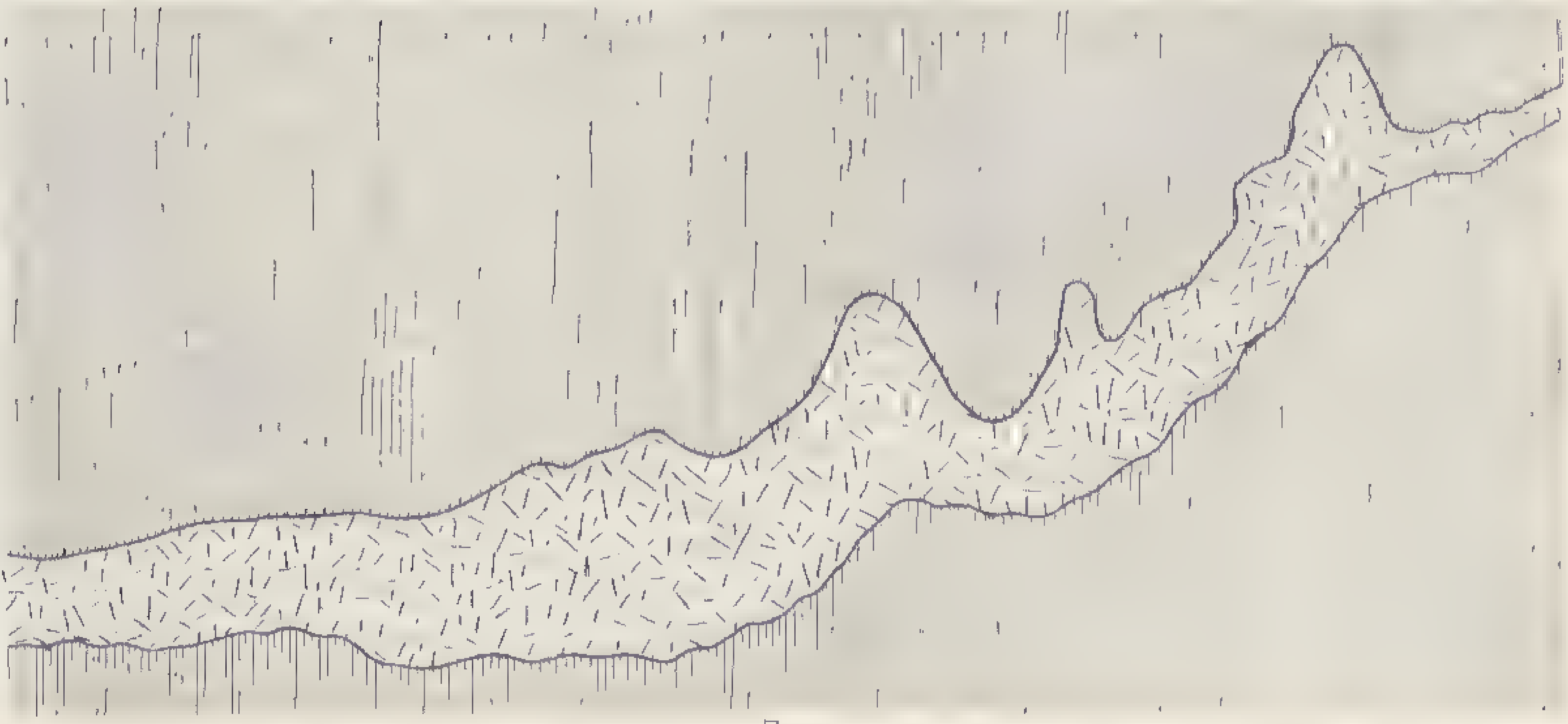


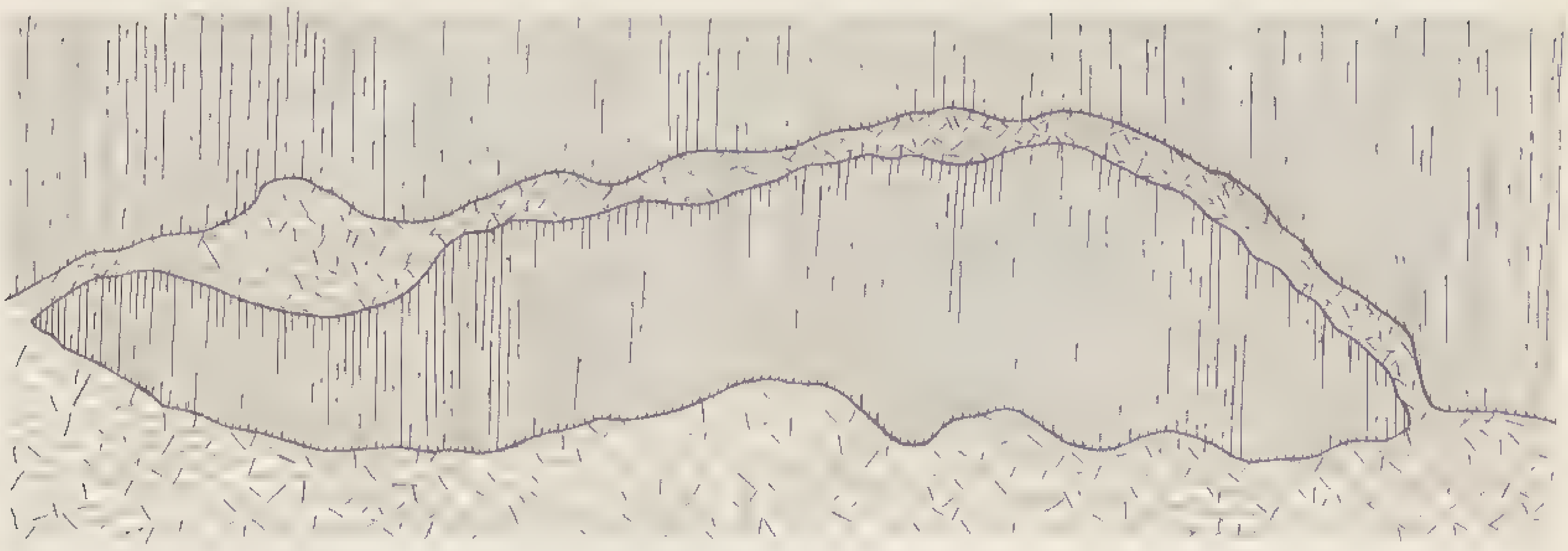
7

PLATE III.

Figure 10 (page 32) represents in section the ore passing around and cutting off a portion of the schist, some six feet in length, from the main body. The ore at the lower portion of the figure was then being mined, the schist forming a *horse* in it. Jackson Mine, Negaunee.

Figure 12 (page 32) shows the relations of ore, which was then being mined, to its overlying schist. This represents a section some twenty feet in length. Jackson Mine, Negaunee.

Figure 13 (page 32) represents a section of a jasper dike in a sandstone. The dike is of irregular width, and approximately follows the stratification of the sandstone in its main course. It sends projections in places out across the laminæ, breaking, contorting, and indurating them. The dike is some fifteen feet in length, and in the figure its width has been greatly exaggerated compared with its length. Home Mine, Cascade Range.



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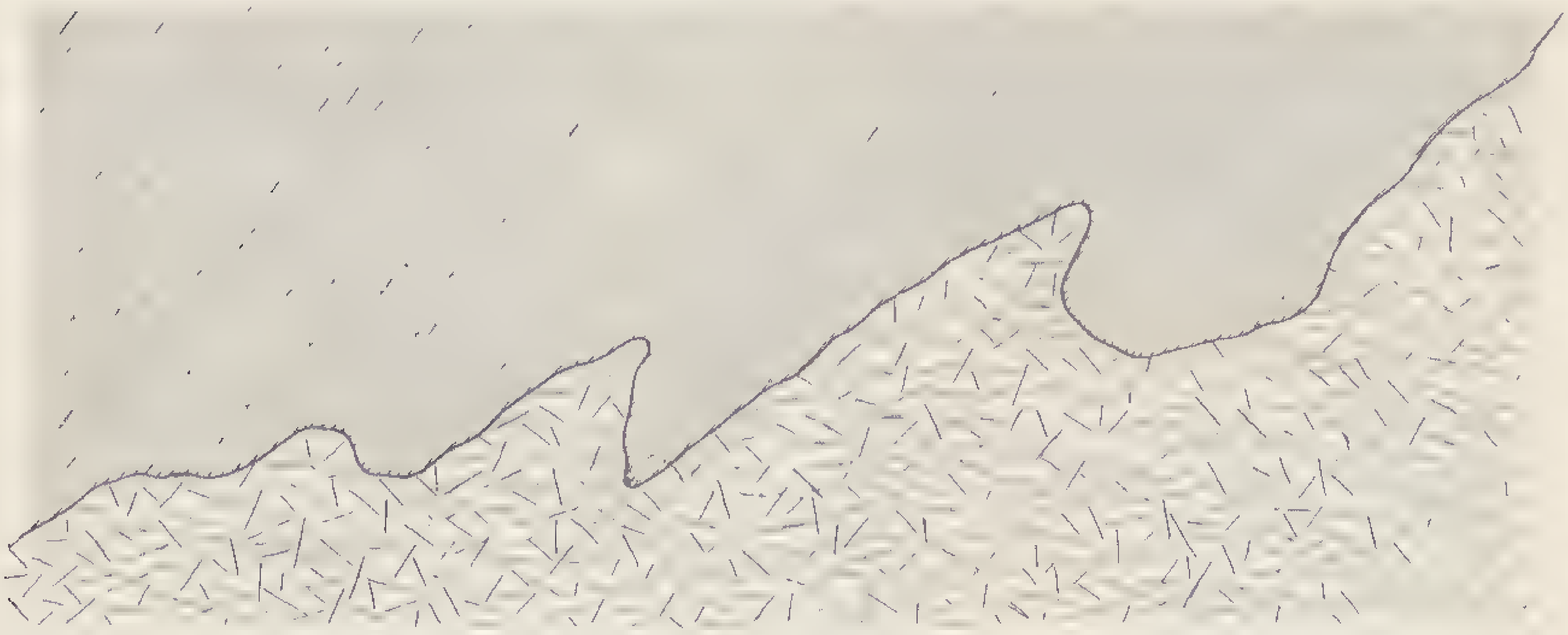

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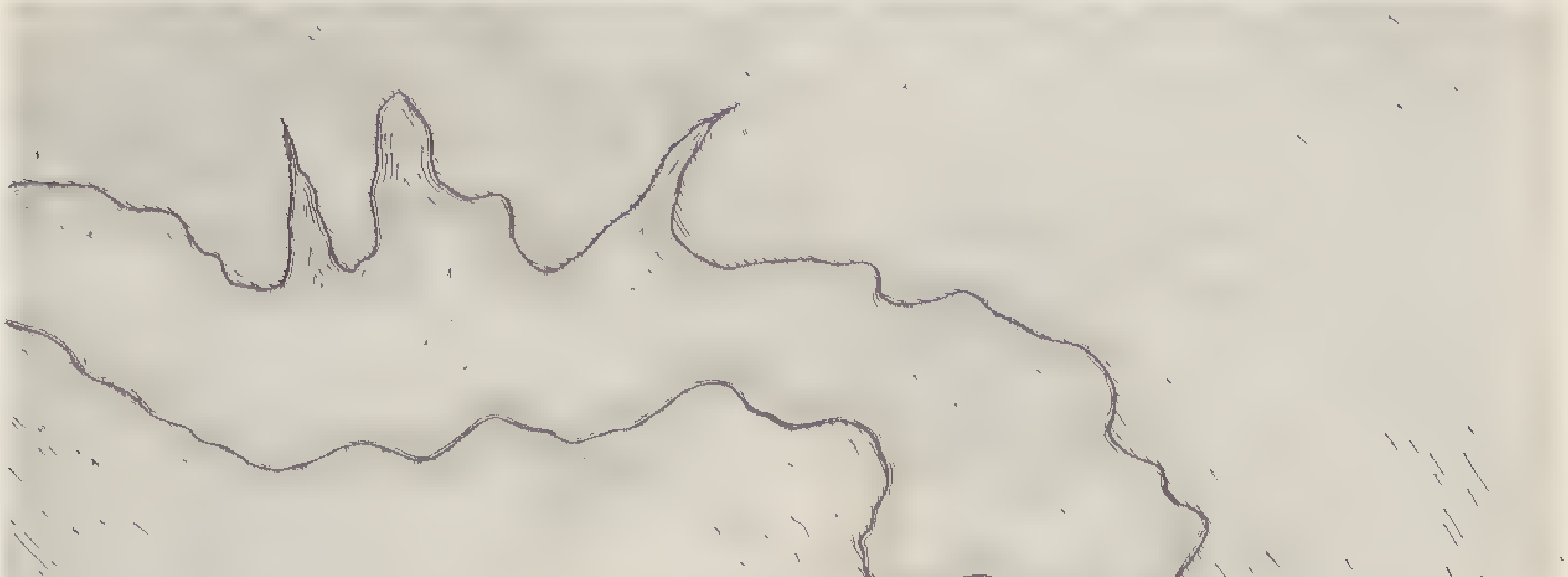

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PLATE IV.

Figure 14 (page 36) represents in plan a "diorite" dike with a tongue extended into the schist. Light-house Point, Marquette.

Figure 15 (page 36) shows in plan the line of junction of a "diorite" with the schist. Quarry near Light-house, Marquette.

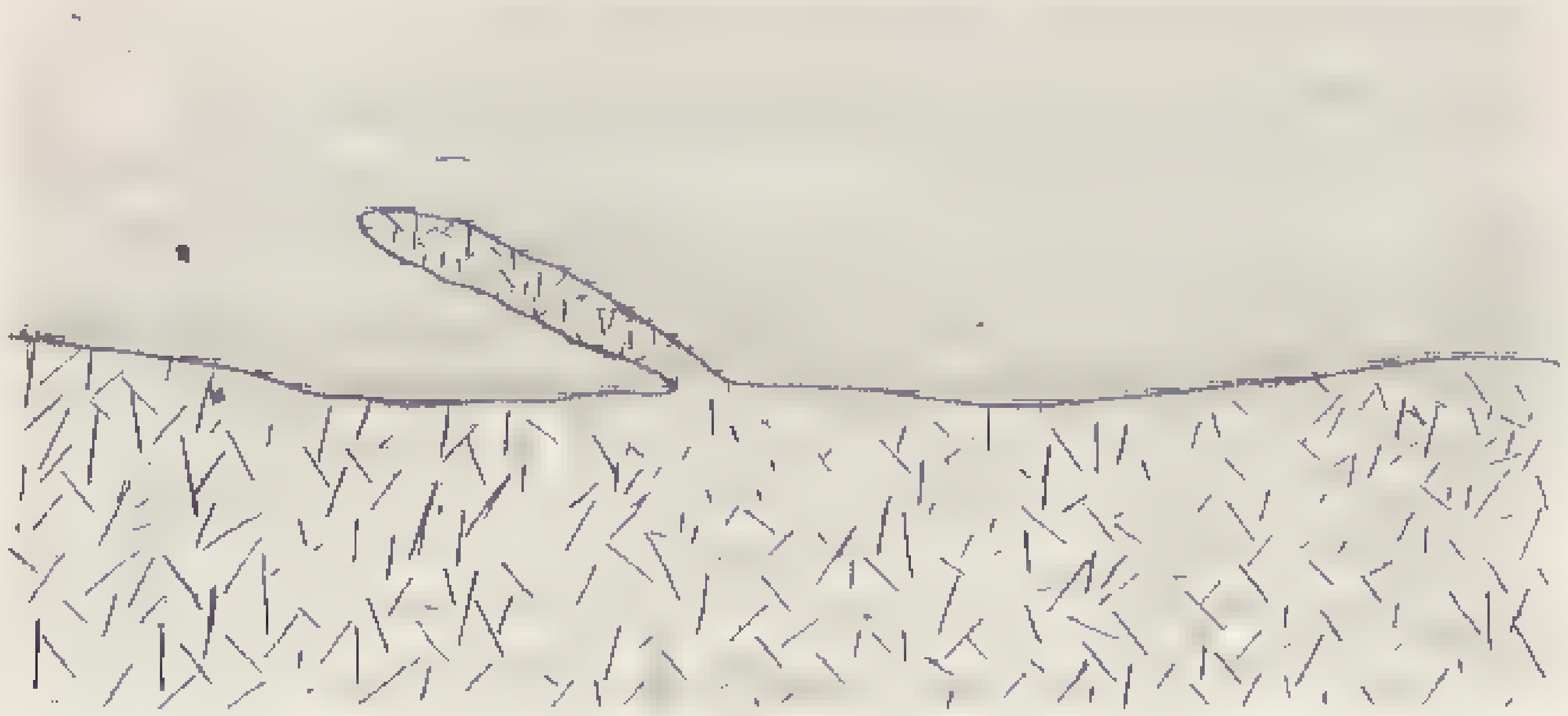
Figure 16 (pages 36, 38) shows in plan the relations of a felsite, represented on the right of the figure by angular marks, to a later "diorite" dike and to the schist. The "diorite" cuts and faults the felsite, but as the portion to the left of the "diorite" is under the waters of the lake, the writer is not sure of the accuracy of that portion of the figure.

Figure 18 (page 41) shows in plan the line of junction between the "diorite" and schist. East of Ishpeming.

Figure 19 (page 41) shows in plan the line of contact between the "diorite" and schist, with an enclosed fragment of schist in the "diorite." Northeast of the Cleveland Mine, Ishpeming.

Figure 20 (page 41) is a section, chiefly ideal, showing the supposed relations of the "diorite" dike to the adjacent schist, at the same locality as Fig. 19.

Figure 21 (page 41) represents in plan the line of junction between the "diorite" and schist. Northeast of the Cleveland Mine, Ishpeming.



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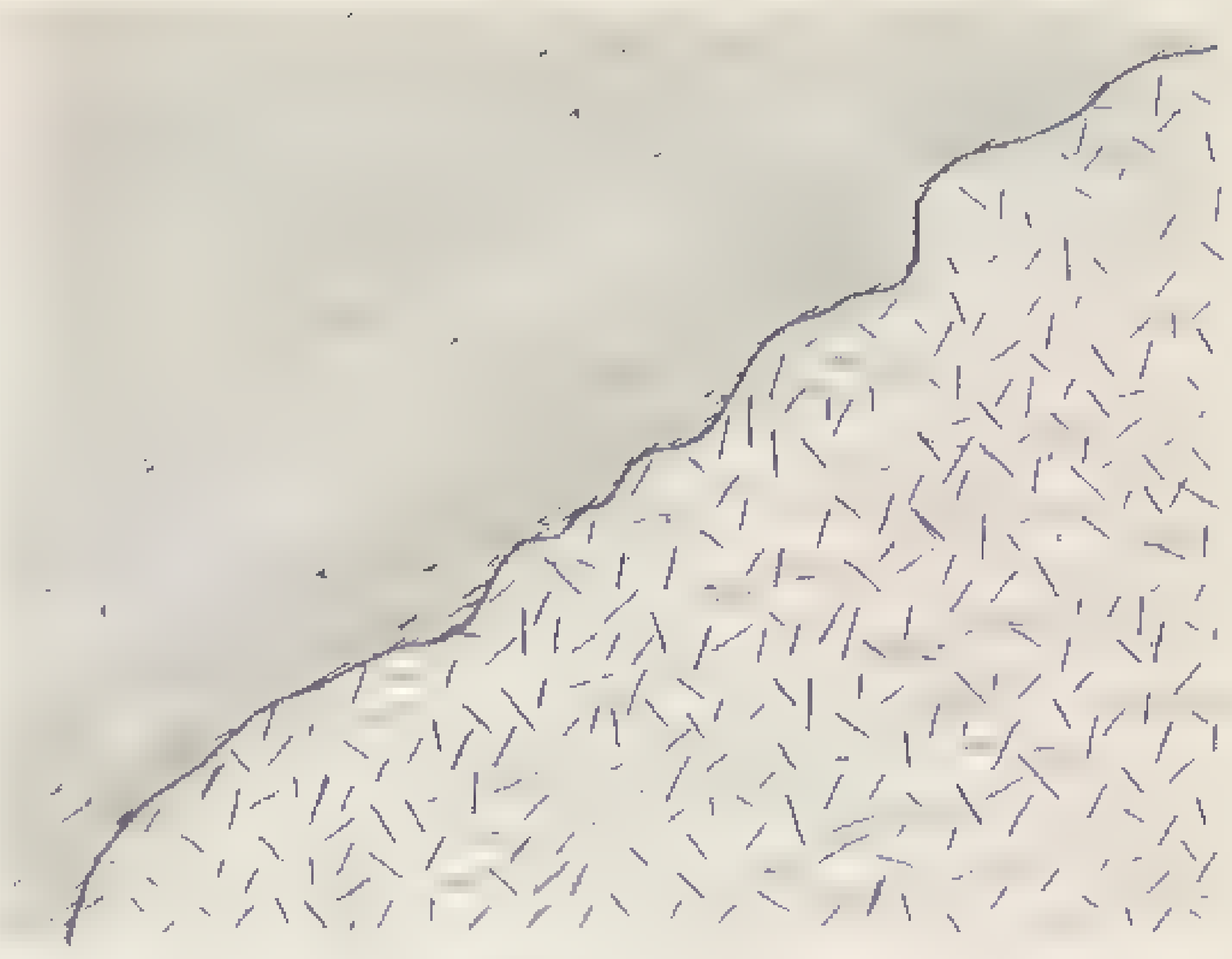

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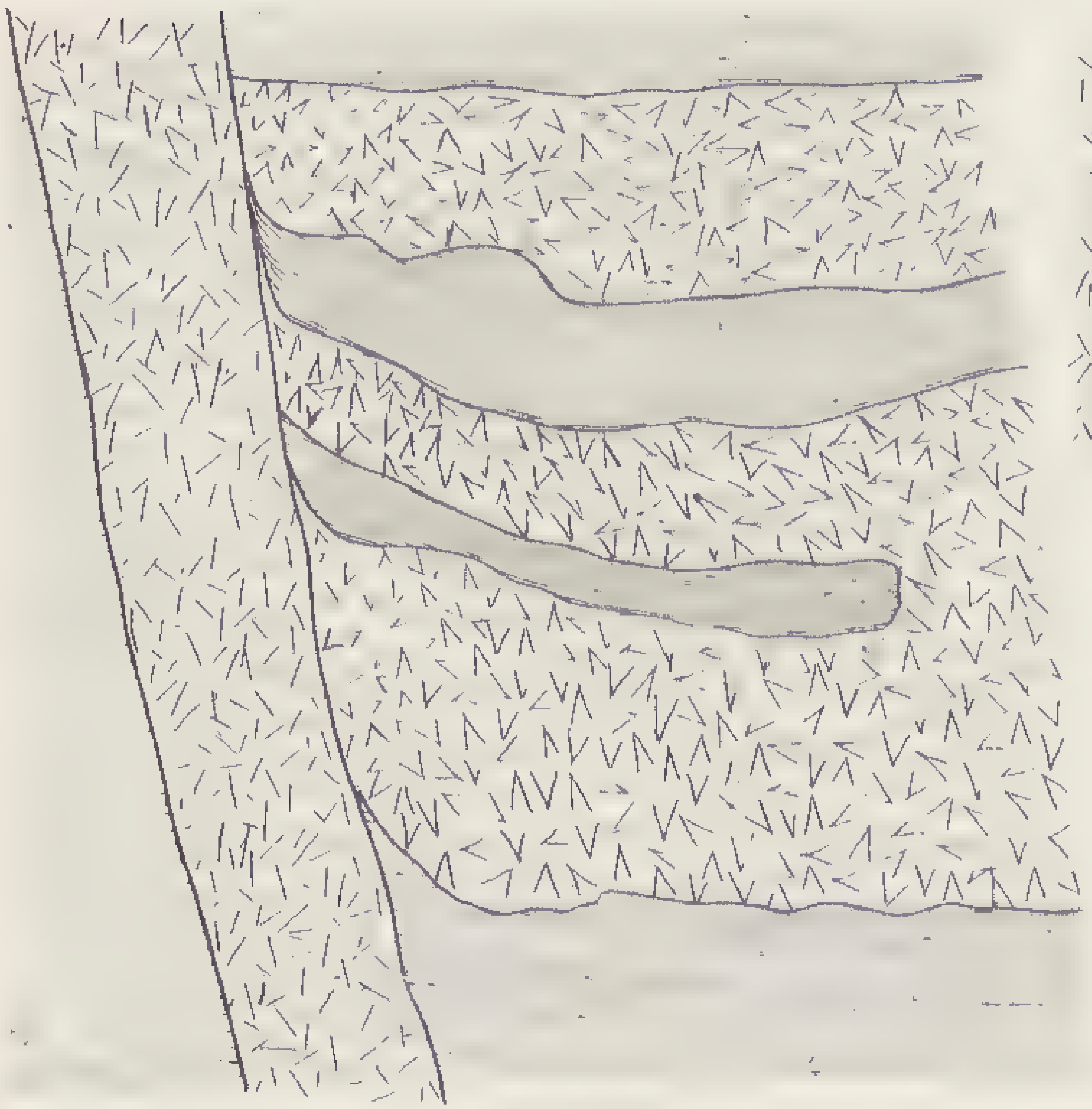

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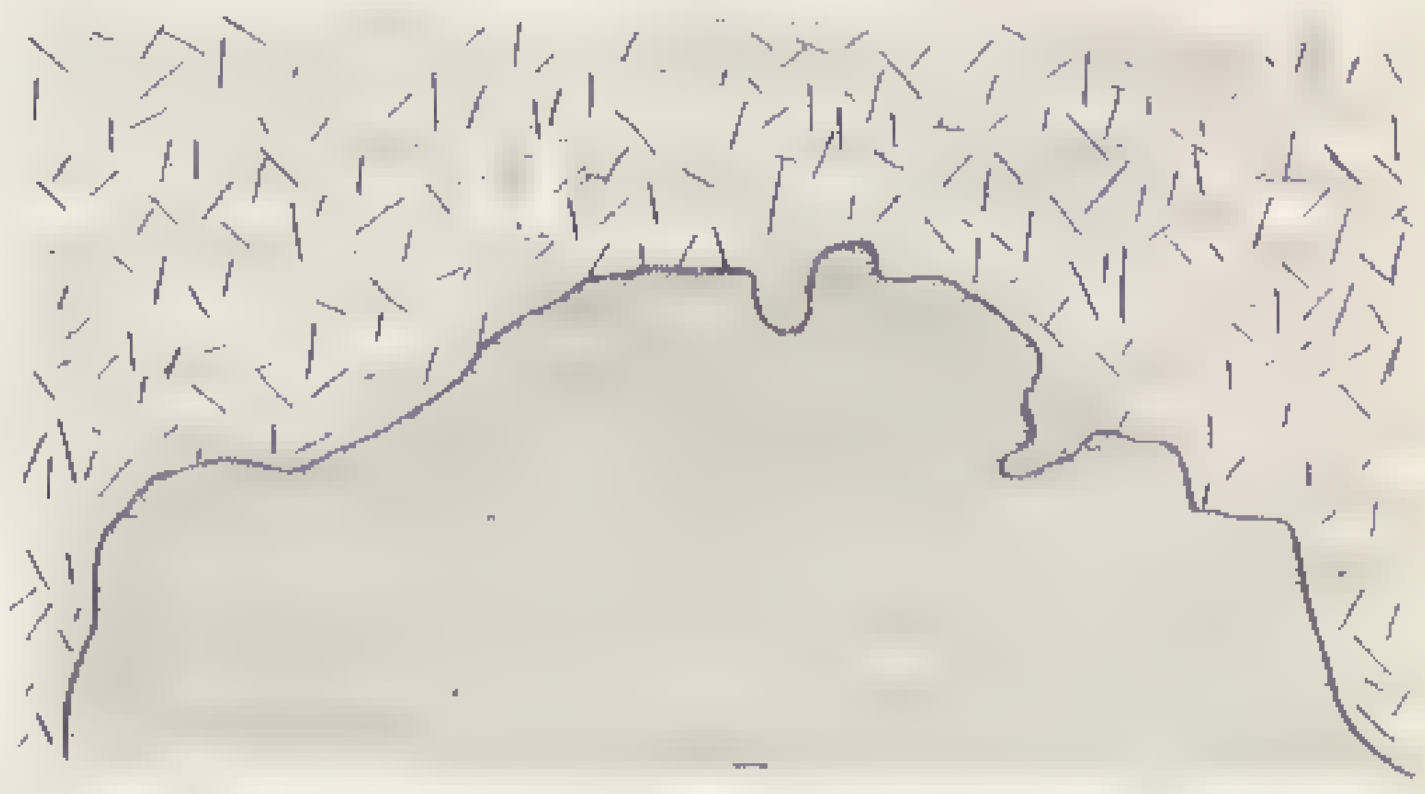

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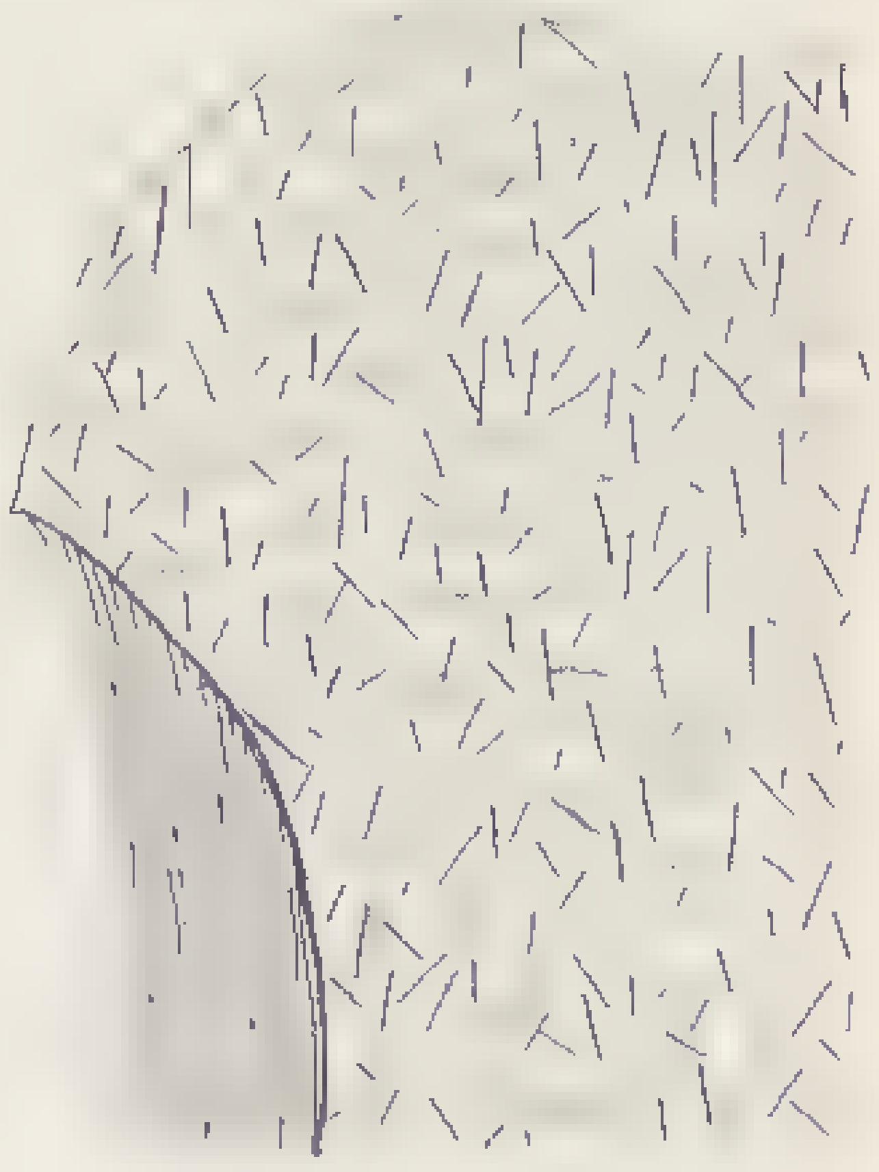

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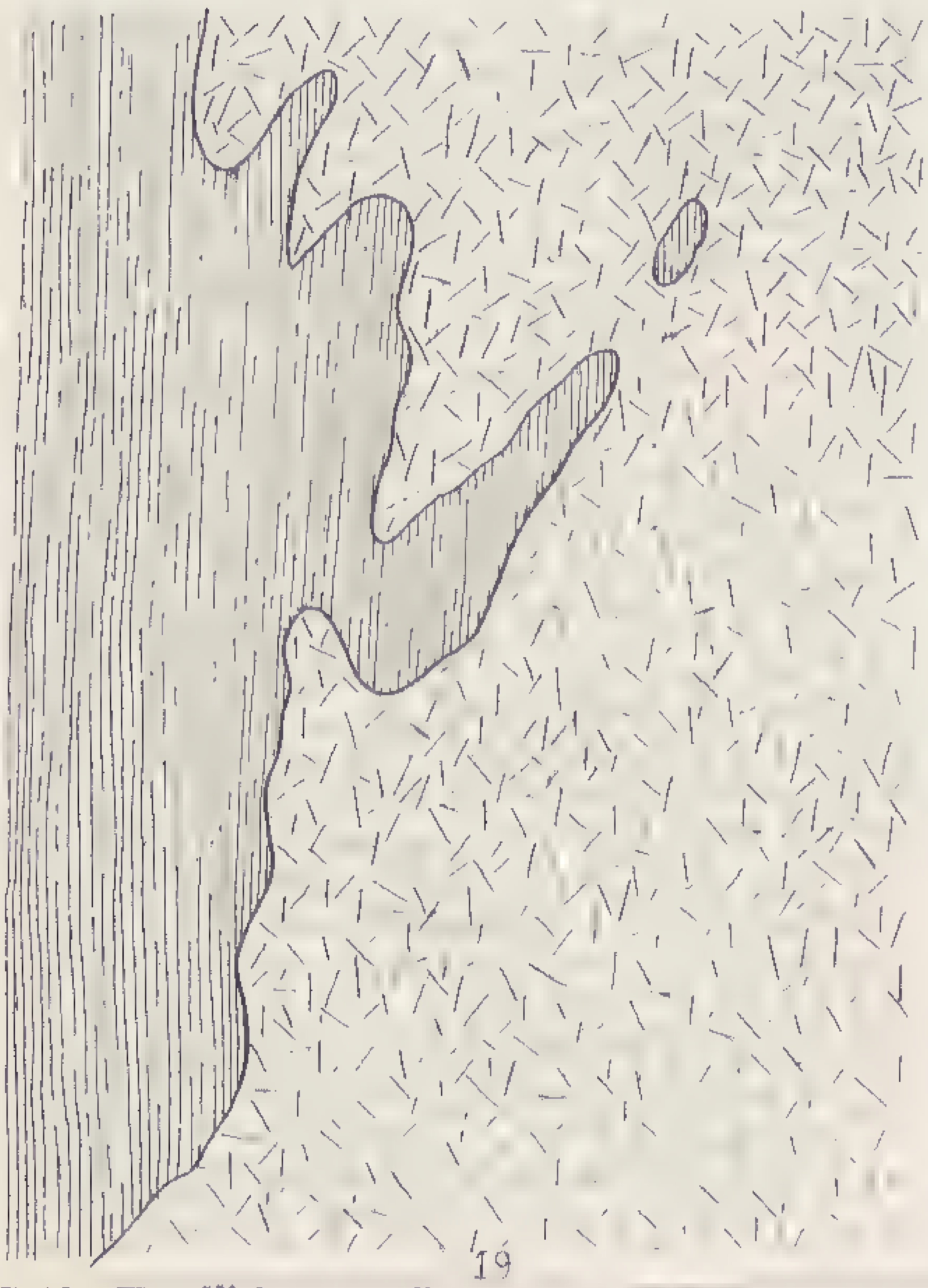

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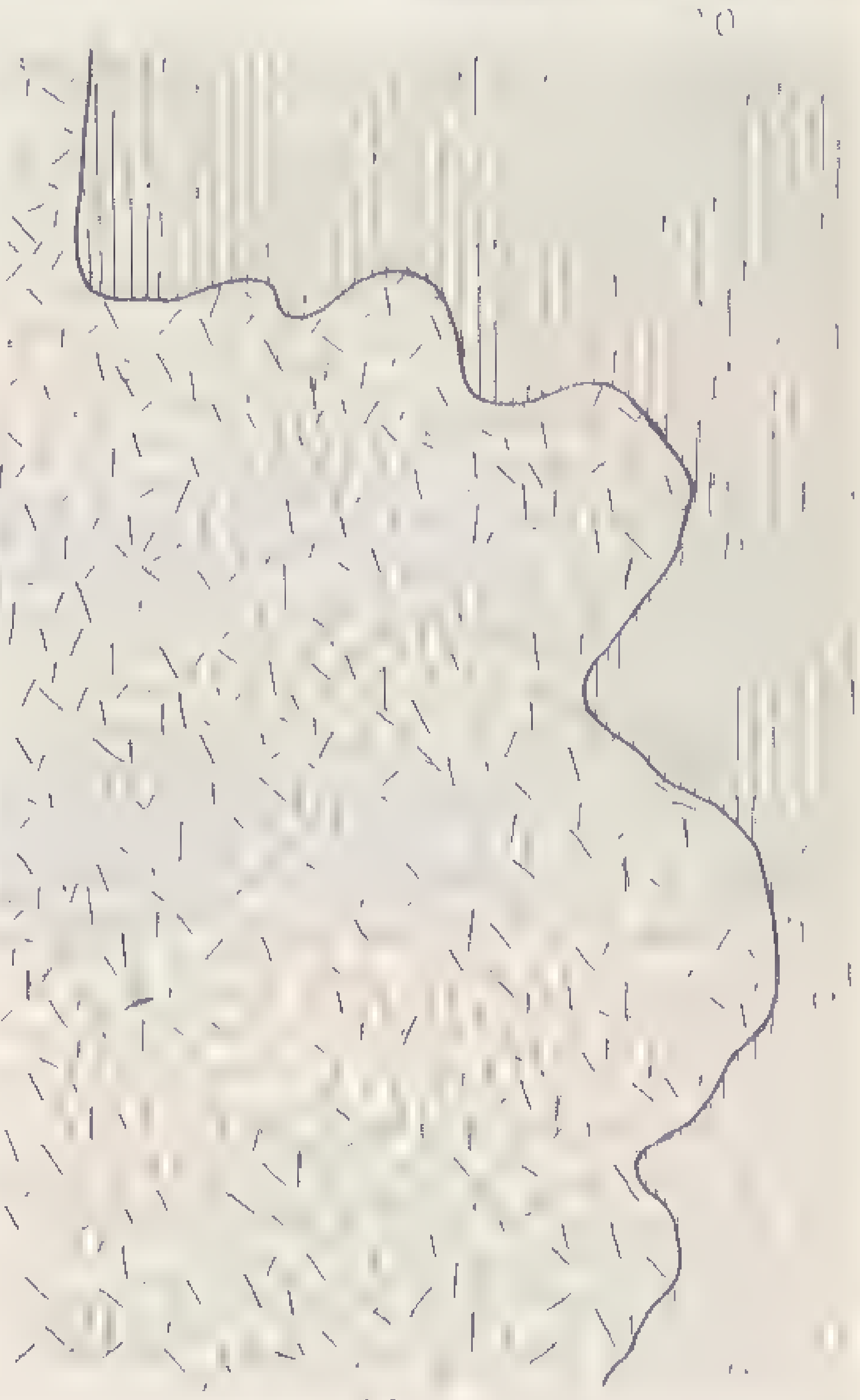

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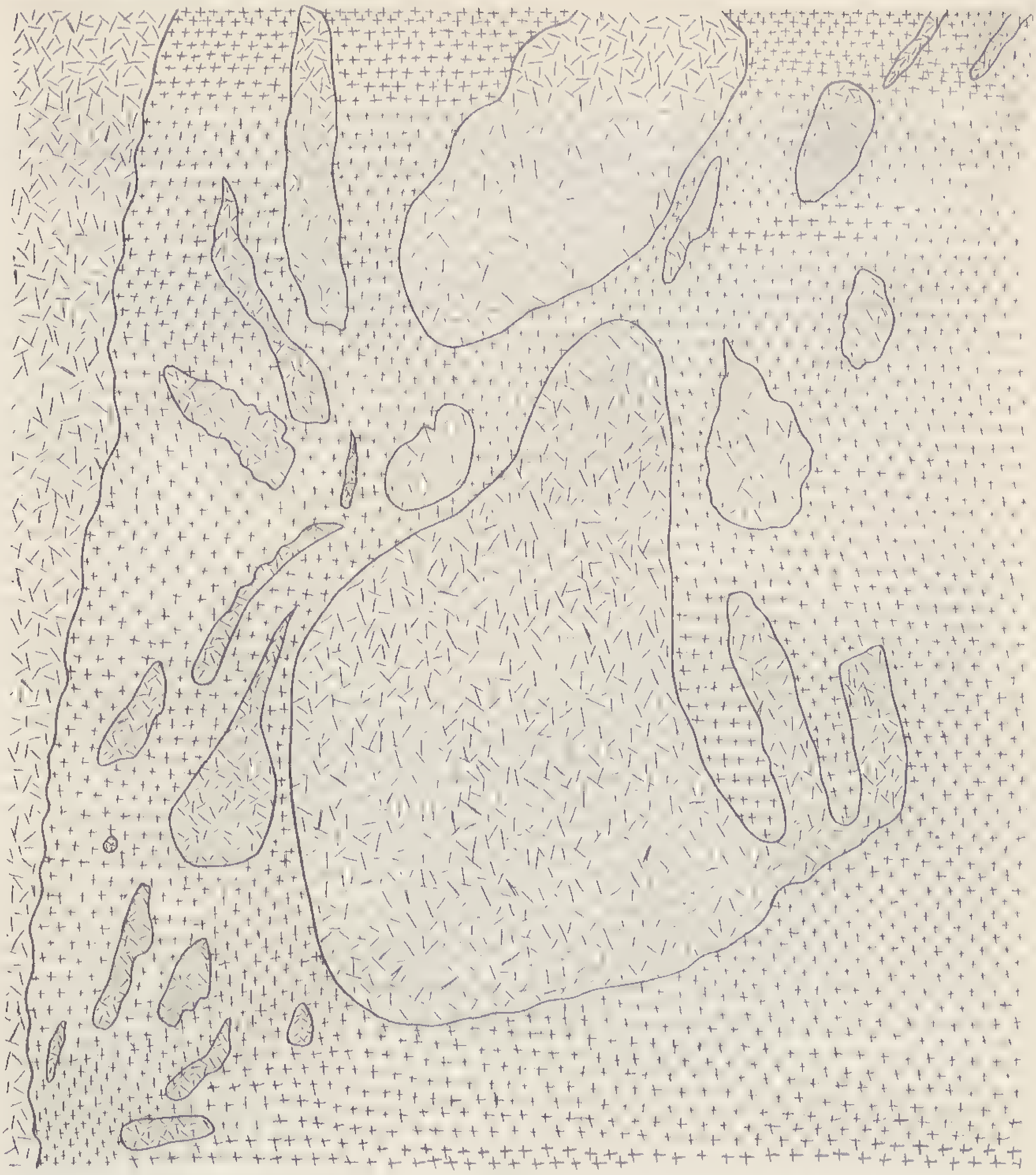
PLATE V.

FIGURE 17 (page 39) shows in plan the relations of the granite denoted by the crossed (+) space to the "diorite." The "diorite" shows in mass on the left, and in rounded fragments in the granite. Picnic Point, north of Marquette.

FIGURE 22 (page 41) represents the line of junction between the "diorite" on the right with the schist on the left. Northeast of the Cleveland Mine, Ishpeming.

FIGURE 23 (pages 49, 50) represents a plan, partly ideal, of a narrow diabase dike cutting a broad "diorite" dike and the schists at Ishpeming. The lettering is explained in the text. Salisbury Mine, Ishpeming.

FIGURE 24 (pages 49, 50) is an ideal section showing the supposed relation of the above "diorite" to the schists. Salisbury Mine, Ishpeming.



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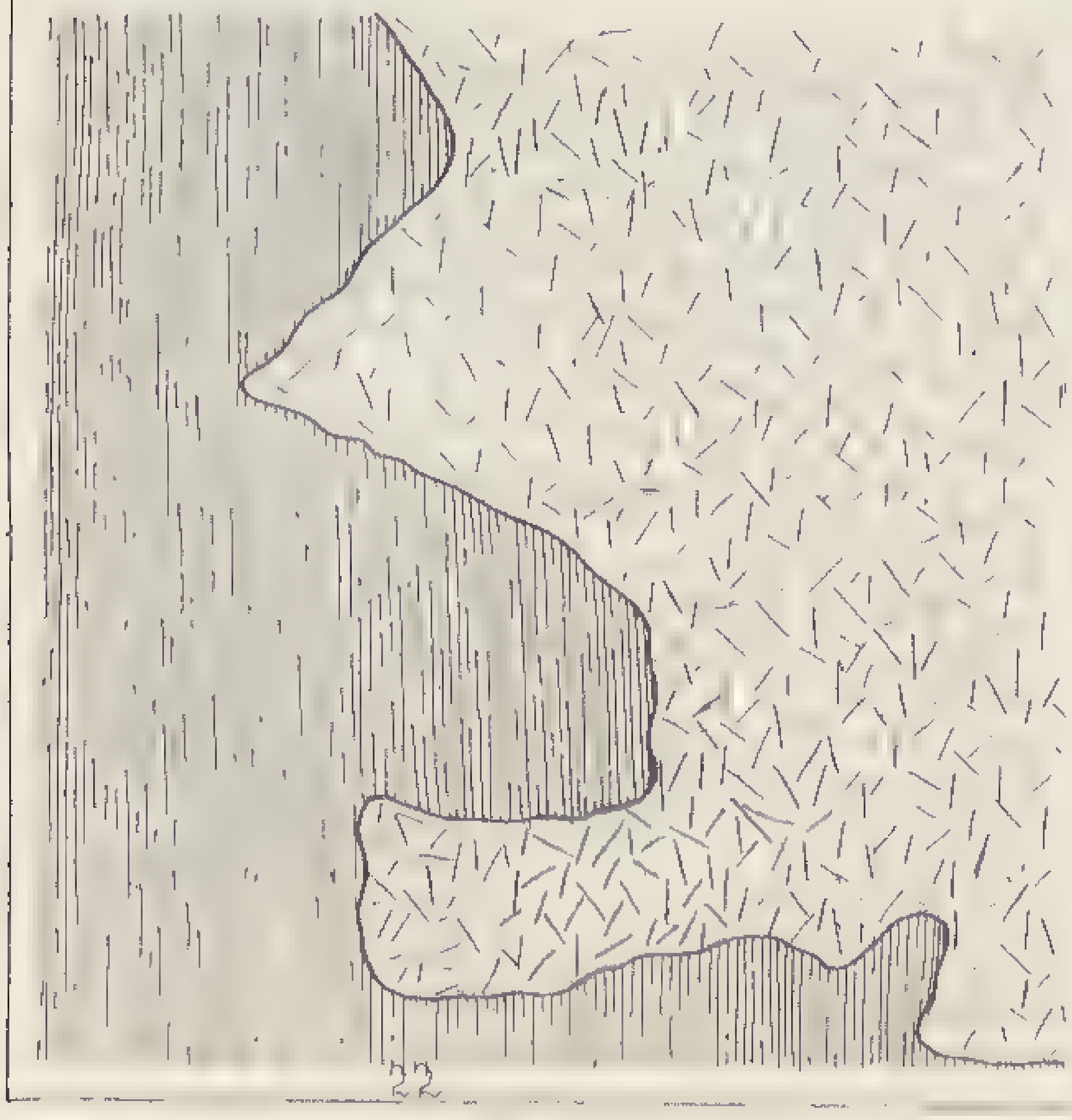

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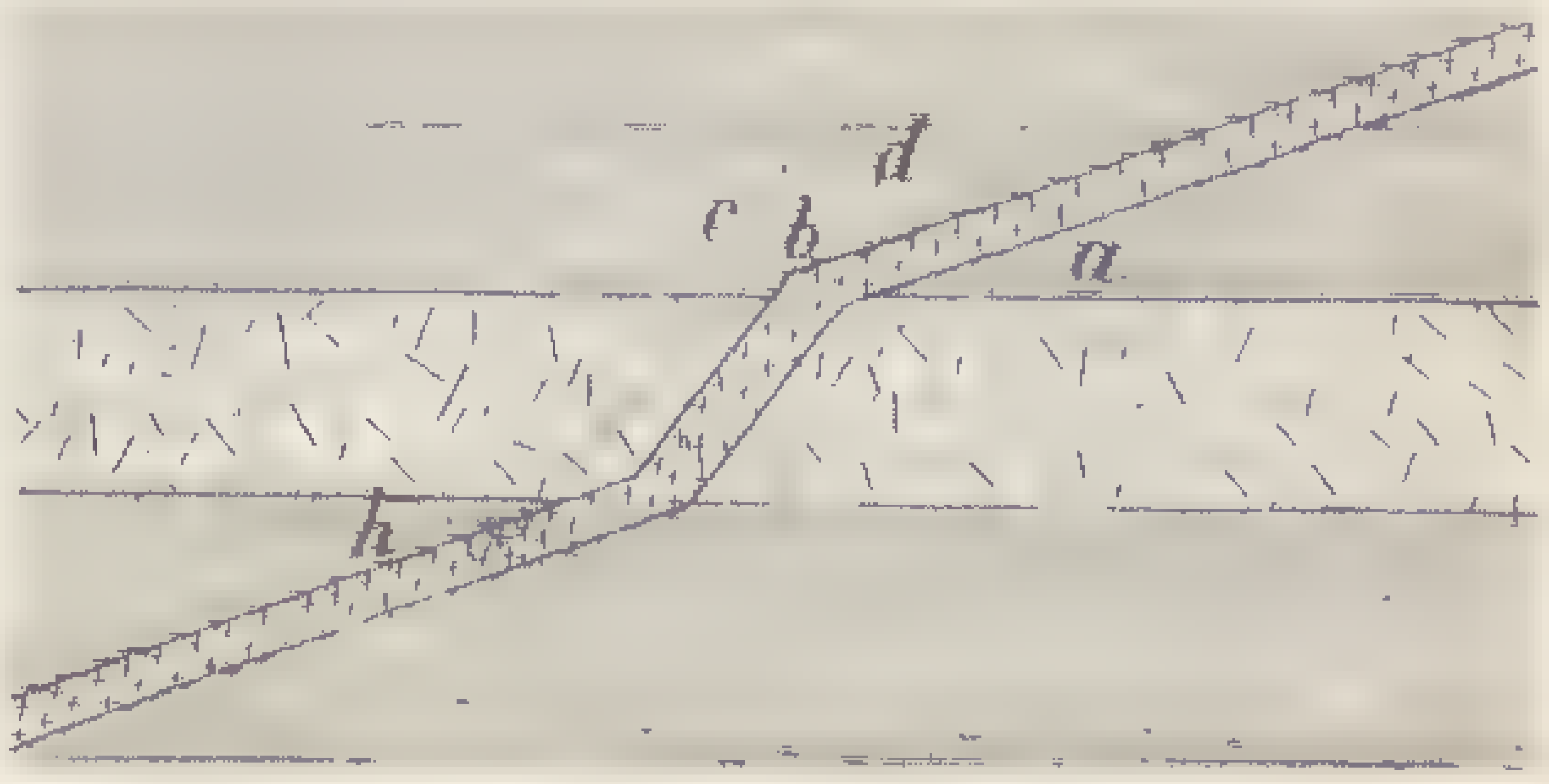

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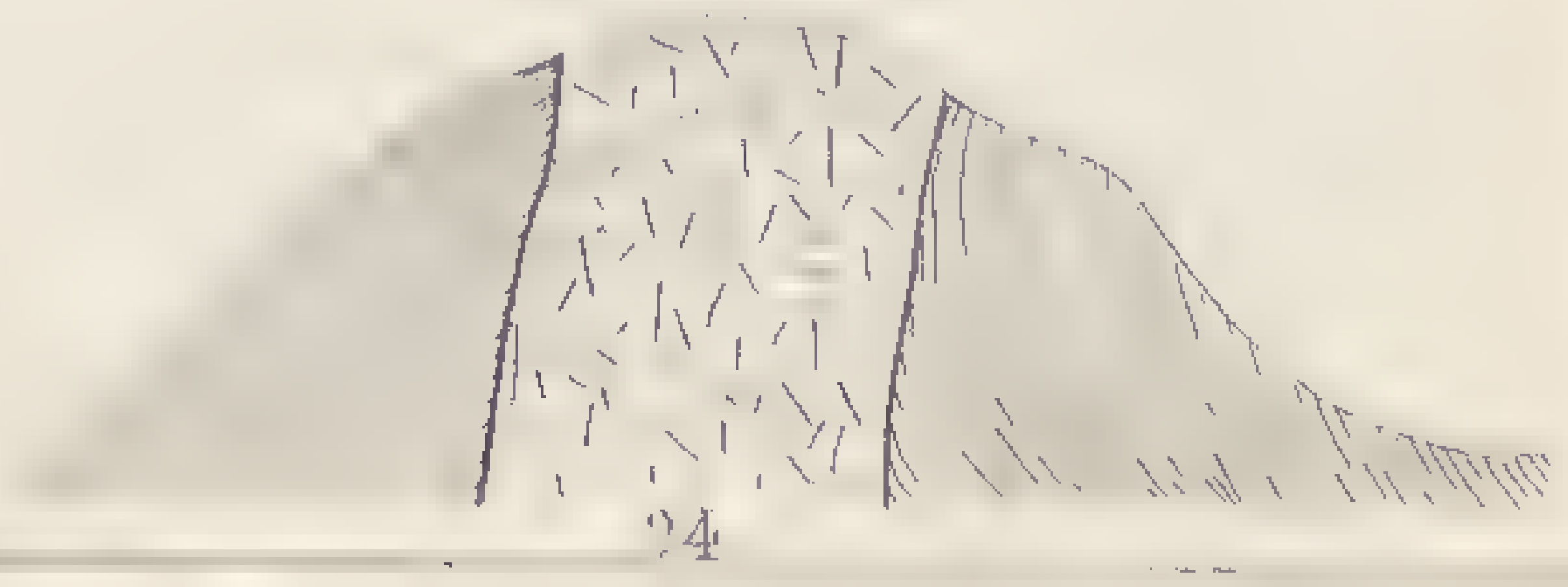

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PLATE VI.

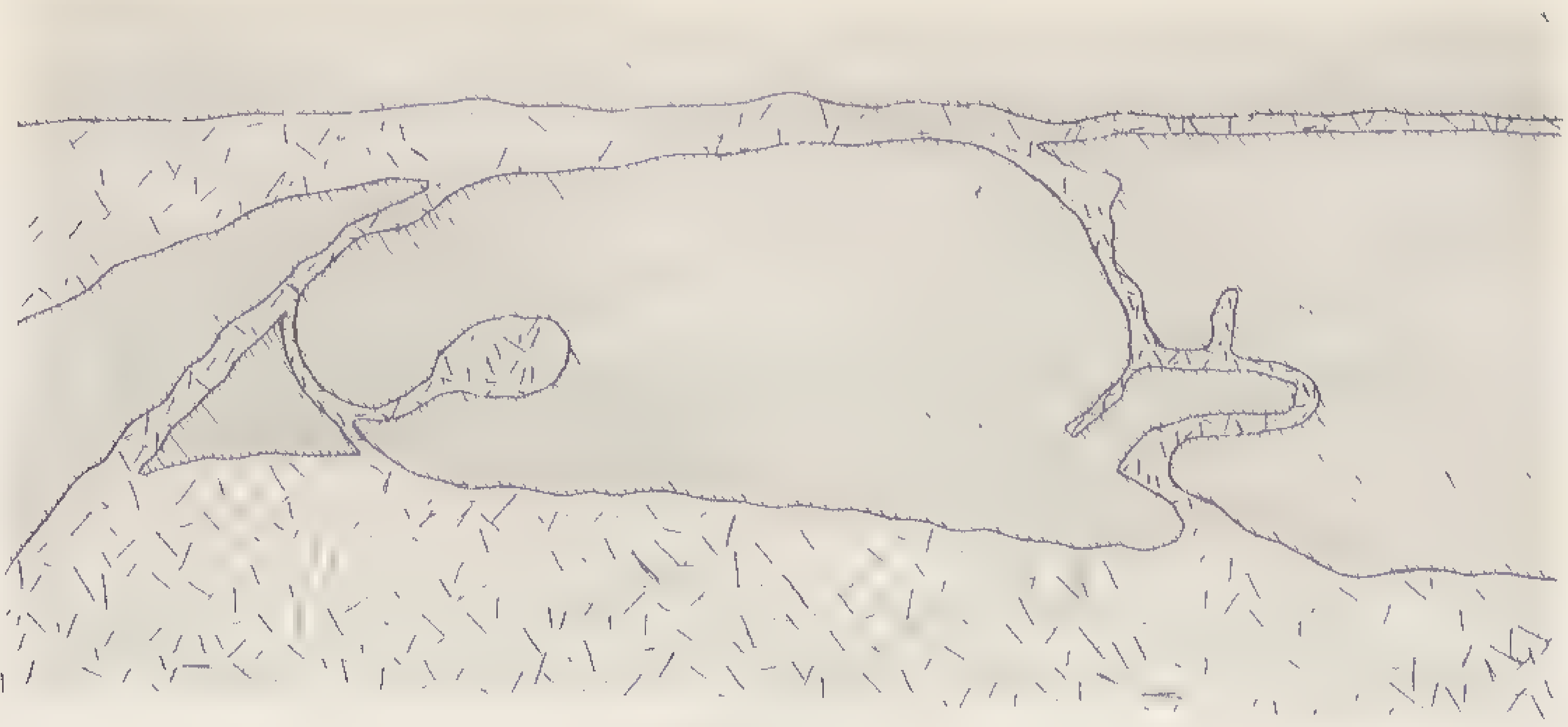
FIGURE 25 (page 51) shows in section the relation of the "soft hematite," represented by oval marks, to the jasper and ore above and on both sides of it; also to fissures which allow the percolation of water, the upper portion of the figure being adjacent to the surface of the ground. McComber Mine, Negaunee.

FIGURE 26 (page 55) shows in section reddish eruptive granite cutting gray gneiss. The granite at the left and bottom of the figure is connected with the main body of the granite. South of Ishpeming.

FIGURE 27 (page 113) represents in section a tongue of trap extending down into the ash-bed, and holding a rounded fragment of the latter. End of drift, Sept. 12, 1879, 5th level. Copper Falls Mine, Keweenaw Point.

FIGURE 28 (page 113) shows the denuded and irregular surface of the underlying sandstone, covered by the overlying lava flow. Emerson Adit, Copper Falls Mine, Keweenaw Point.

All the figures, except when otherwise stated, are from free-hand sketches made in the field from actual observed occurrences. No attempt has been made to draw to scale, or to show anything except the actual relations of the rocks to one another. The sketches were redrawn by the writer, engraved on stone by Mr. L. Trouvelot, and printed by A. Meisel.



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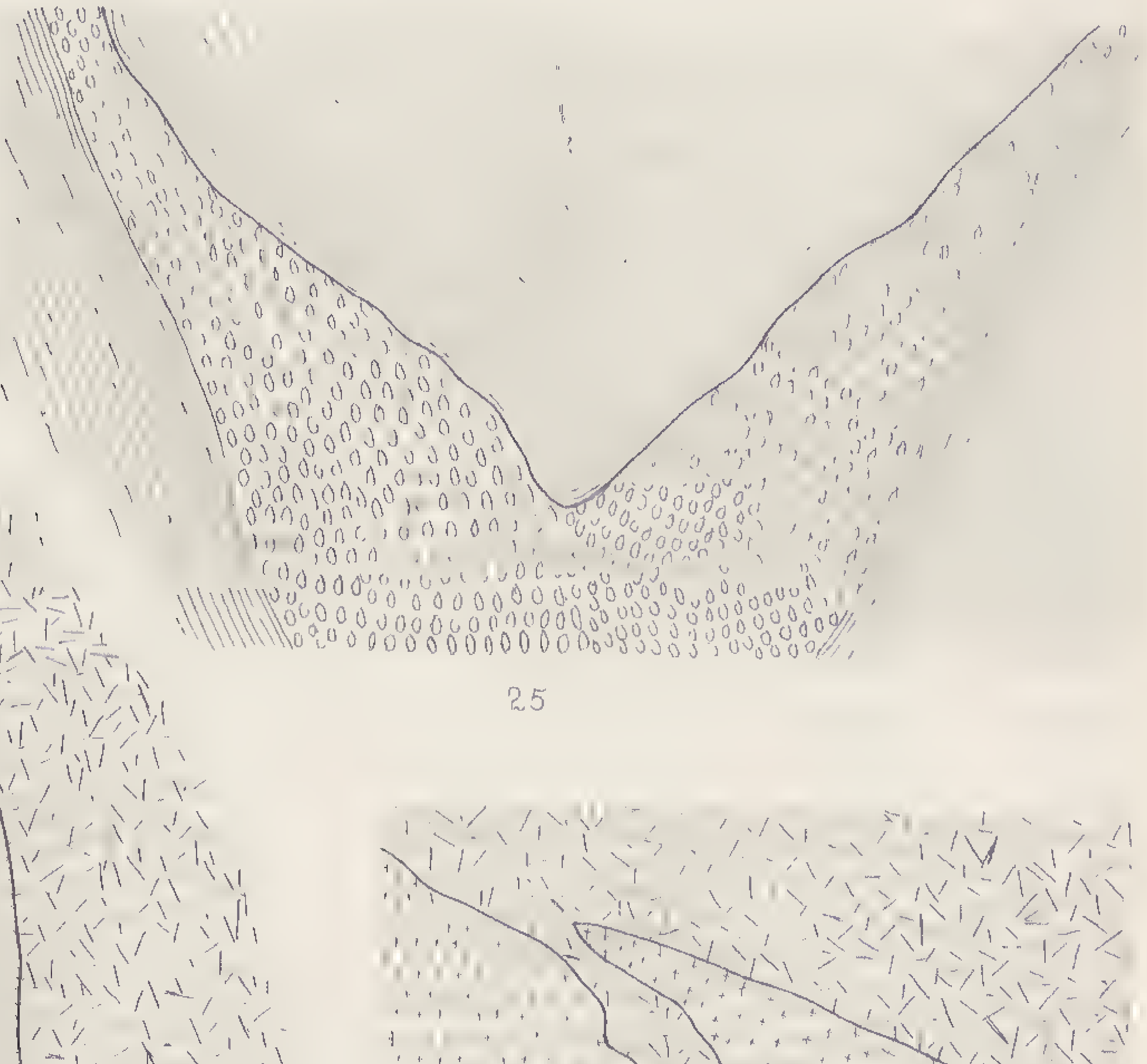

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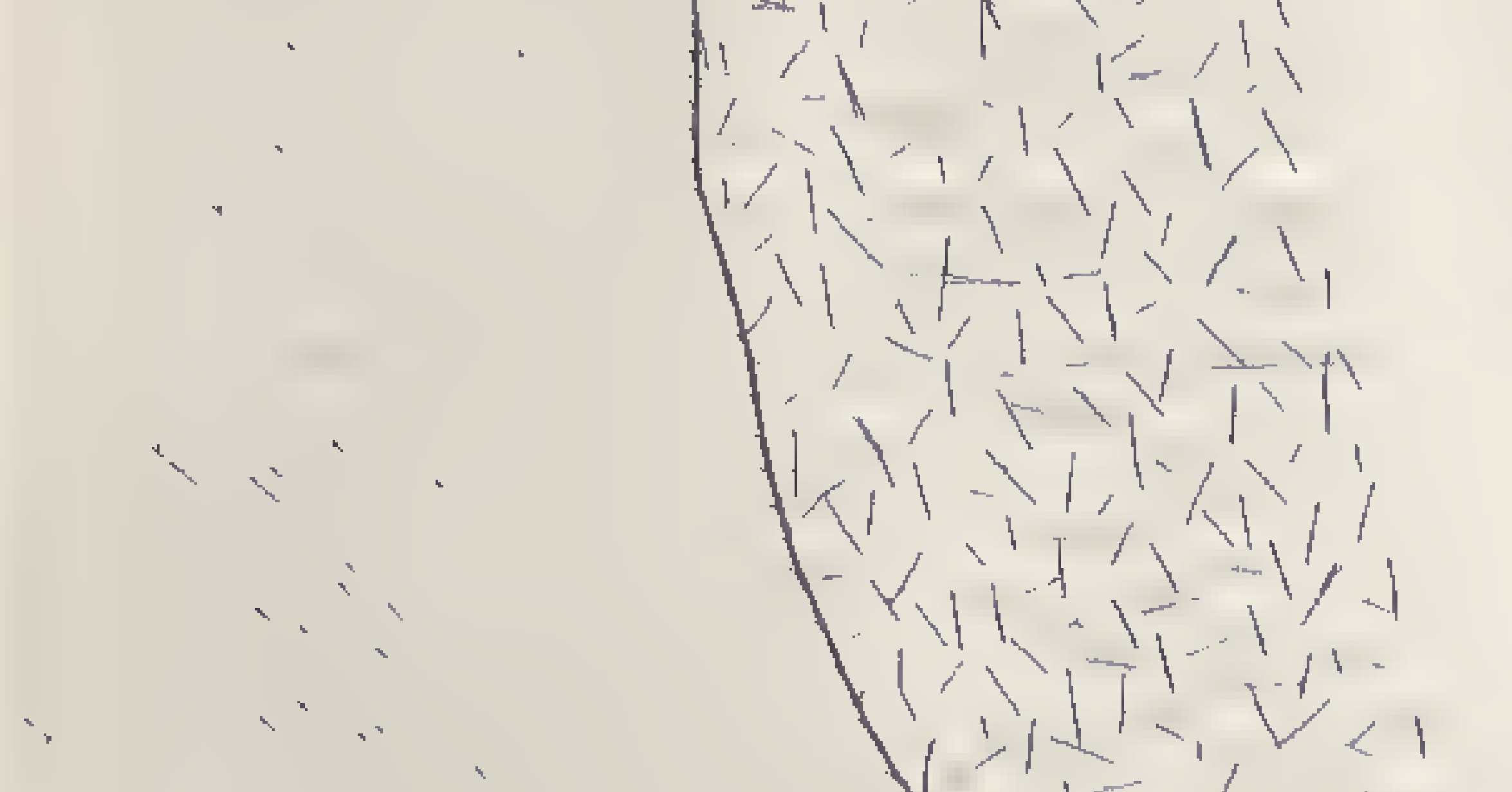

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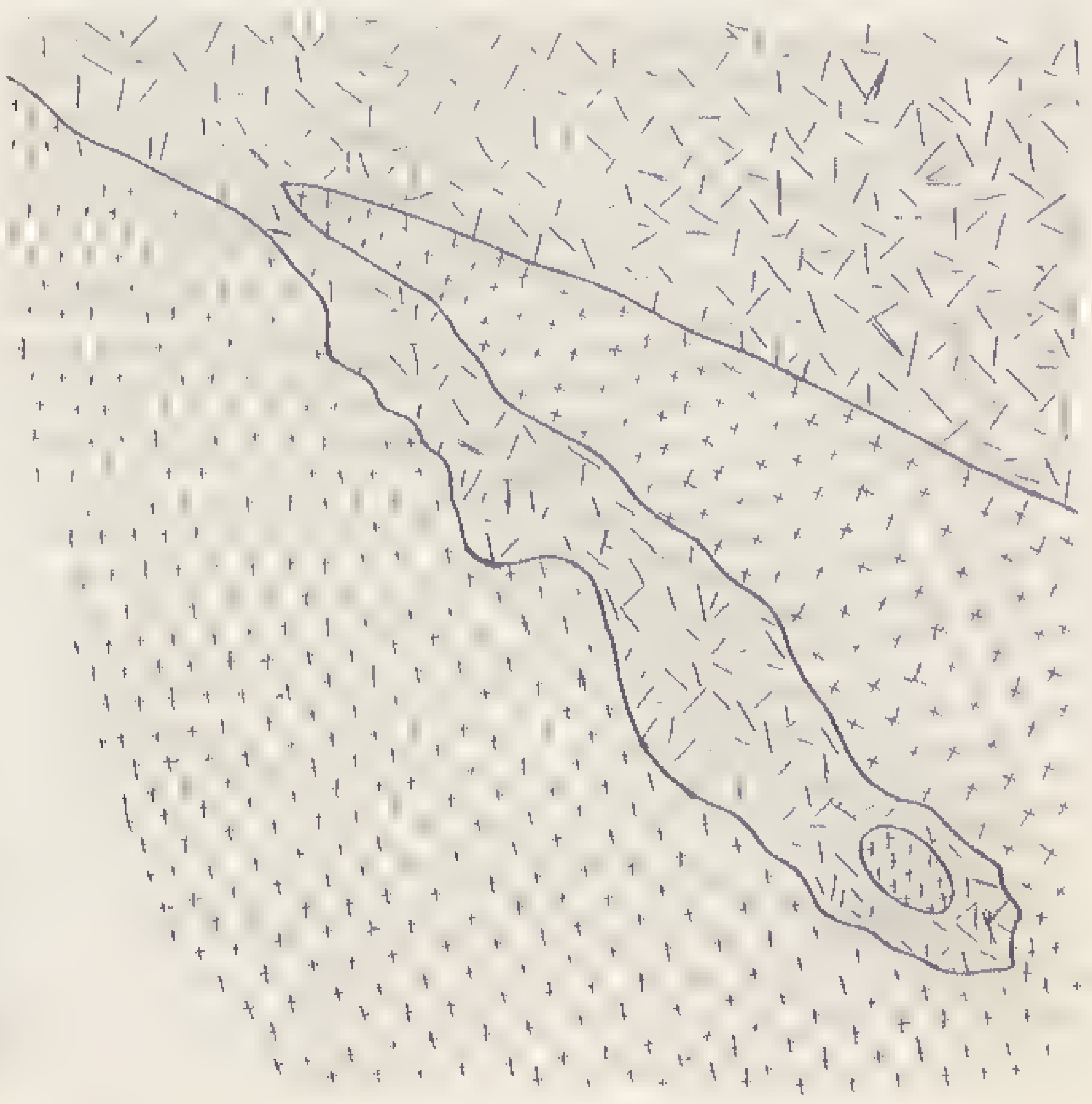

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No. 2.—*The Felsites and their Associated Rocks North of Boston.*

By J. S. Diller.

The extremely interesting and complicated petrology of Eastern Massachusetts has been the subject of a great deal of discussion, and at no time in the past have opinions concerning the origin and relations of the rocks been more at variance than at present. It is important, therefore, that the facts to be found in nature be carefully observed and described in order that the various differences of opinion may, as far as possible, be removed and the truth demonstrated. There are, however, certain localities whose facts appear, under the eyes of some observers, to be very different from those seen by other observers in the same place; and it seems necessary in such cases, where the facts are questioned, to describe them with more than usual detail.

The field we have explored includes Melrose, Malden, and the southern portions of Medford, Stoneham, Wakefield, Saugus, and Lynn. Within this area felsite is the chief rock, and with it are associated, besides a complex group of tufaceous rocks, commonly called breccias, a group of stratified rocks, granites, diorites, slates, and diabases. The recent "Contributions to the Geology of Eastern Massachusetts," by W. O. Crosby, contains a map upon which the general distribution of the rocks, so far as we know, is quite correctly given; but, as Mr. Crosby is doubtless well aware, there are many places, and some of them important, too, where the map is in error. We cannot expect to have for many years to come a very accurately detailed geological map of this neighborhood, for even if we had, what we have not, a correct topographical map to use as a basis of geological work, the extreme complexity of the rocks, together with their highly altered condition and the existence of quite extensive covered areas must necessarily require a long time for correct delineation. In determining the relative age of eruptive rocks we have been guided by the generally accepted criterion, viz. that of two rocks, the one which penetrates the other in dike-like masses or contains fragments of the other is the younger. In considering the rocks associated with the felsites, we shall notice them in the order of their ages, beginning with the oldest, and endeavor to describe the facts apart from theoretical considerations.

Stratified Group.

The name *stratified group* is applied to certain rocks whose only common character is that of stratification; and although the rocks of the Boston basin, and also some of the so-called breccias, are distinctly stratified, there is no difficulty in separating the first group, at least geographically, from the others, for its distribution is widely different. The stratified group, consisting chiefly of quartzite and argillaceous rocks, forms an important area, extending from Medford northeast across Spot Pond and Melrose into Saugus. It is a long, narrow band, and fortunately it adjoins the granite, felsite and diorite, so that we have upon the borders of this area the means of determining the relations of all of the rocks mentioned. The petrological relations of this group and its probable much wider distribution upon the surface in former times will be considered later.

Granite.

The granite occupies a large area in Medford southwest of Spot Pond, and also in the eastern part of Melrose, extending into central and northern Saugus. In Malden there are four small areas of granite, one near Pleasant Street between Malden and Medford, another northeast of Prospect Hill, a third along the Newburyport turnpike north of Broadway station, and a fourth near Franklin Park.

The relation of the granite to the stratified group is shown by many facts so evident, that, as far as the phenomena themselves are concerned, there is no difference of opinion among observers.

North of Howard Street, along the Melrose-Saugus line, and at other places, the granite occurs in oblong or irregular patches, apparently as an eruptive in the stratified group. The facts in these cases are, however, not as convincing as others so abundant throughout the regions in which the granites predominate. It has been frequently observed that upon Marblehead Neck the coarsely crystalline granite contains fragments of distinctly stratified rocks. In the granite of Medford stratified fragments are abundant, and sometimes at a considerable distance from the nearest large outcrops of their parent rock. This is especially the case with those found near the western base of Pine Hill. The granite in a beautifully glaciated exposure near the west end of Long Pond, Melrose, envelops several angular pieces of rock in which the stratification can be readily traced. Similar phenomena may be observed upon the western shore of Pranker's Pond, Saugus, and Wenunchus Lake, Lynn. A very fine example of stratified inclusions within the granite has been pointed out by Mr. Crosby * at Break-heart Hill, Saugus. The best exposures at this locality are not far from Forest Street, on the west side of a private road leading from Mr. Artemus Edmond's northward towards Pleasant Lake. The coarse-grained granite makes very clearly defined contacts with the stratified rocks which it envelops, and the fragments in which the stratification is prominent are large and numerous, and the facts so evident that they cannot be questioned. It is interesting to notice that the strike and dip of the planes of stratification are about the same in all of the enveloped fragments (strike N. 5° – 10° E. Dip 90°). This phenomenon is developed in a very remarkable degree about half-way between Oakland Vale and Long Pond, where the granite is full of elongated fragments whose stratification is nearly vertical, and whose strike is approximately N. 40° E. This direction corresponds very nearly to a sort of gneissoid arrangement of the minerals in the coarse granite of adjacent localities where the fragments do not occur. Almost all the varieties of rocks which occur in the stratified group are represented by fragments in the granite. The fragments vary in size from an inch to many feet in length, and are generally more highly metamorphosed than the large mass of the group from which they were derived. The quartzite, although occurring in very well marked fragments, is not nearly so abundant as the less silicious varieties.

It is probable that the position of the fragments, in some cases at least, as well as the gneissoid structure found in the same region may indicate the direction of motion in the enveloping mass at the time of its extrusion. The general distribution of the fragments of the stratified group, throughout a greater portion of the granites we have examined, forces us to admit, either that the granites have moved quite a long distance from the present outcropping stratified group, or else that the latter group at the time of the eruption of the granites had a wider distribution. The large dike of diabase at the west base of Pine Hill, Medford, contains quite a number of fragments which closely resemble the quartzite of the stratified group. If they are fragments of quartzite from the stratified group, they must have been brought from beneath the surrounding felsite, either from the stratified group in place, or an included fragment in the granite. Such facts render it probable that before the granites and felsites reached the surface, the stratified group had a much wider distribution than it has at the present time.

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* Contributions to the Geology of Eastern Massachusetts, p. 39.

Felsite.

The felsites, extending from Medford through Malden, Melrose, and Saugus to the eastern part of Lynn, and northward from Melrose into Wakefield, are the prevailing rocks of that region. Their petrological relations have been one of the chief enigmas in the geology of Eastern Massachusetts, and, judging from the present diverse opinions, much thorough work needs to be done before a final solution is reached. Most observers agree that the felsites are of more recent age than the granites; nevertheless, there is a wide difference of opinion concerning the phenomena upon which this common conclusion is based. Some observers maintain that the felsite is younger than the granite, from the fact, as they say, that the felsite not only envelops detached fragments of the granite, but also penetrates it, in the form of distinct dikes. Other observers reach the same conclusion, because, in their opinion, the granite envelops felsitic fragments, and in the form of irregular dikes penetrates the felsite.

It is evident that theoretical considerations are of little value unless supported by facts, and for this reason the latter should be clearly set forth and particularized, apart from theories, so that there may be some hope of securing, ultimately, a uniformity of opinion concerning at least what occurs in the field.

As far as our observations have extended, we have never seen an example of the granite breaking through the felsite or enveloping its fragments. In every case in which we could determine the relations of the rocks the felsite occurred as an eruptive penetrating the granite.

Before proceeding to point out the special localities in which the granite is cut by the felsite, let us consider the evidence, apart from the dikes, which proves the truly igneous nature of the latter rock.

Upon Break-heart Hill in Saugus and to the west towards Main Street there occurs an extremely heterogeneous mixture of banded felsite with grayish fragmental material, which in its external aspect resembles, to a considerable extent, ordinary ashes. The true nature of this grayish rock was not suspected until the microscope revealed the fact that it contains many of the splinter-shaped or chip-like sharp-edged fragments whose peculiar forms belong to the volcanic glass of rhyolitic tufas. The forms are so characteristic, and in this case so well preserved among the other ashy material, that there can be no doubt of their identity. The fragments, as we would expect,* are no longer volcanic glass, but quartz, which is the product of alteration. The composition of this interesting rock, and its petrologic relations, we believe, establish beyond question that it is a veritable ancient volcanic ash. There is considerable evidence, though not yet decisive, for want of further microscopical investigations, that these ashes are distributed in patches throughout a considerable portion of the region occupied by the felsites.

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* On the Classification of Rocks, by M. E. Wadsworth; Bull. Mus. Comp. Zoöl. at Cambridge, Mass., Vol. V., No. 13.

It seems to be certain, therefore, that there has been within this region a true volcanic outburst by which the ashes were produced, and that anterior to the formation of the ashes, or perhaps about the same time, there was an eruption of felsitic lava, with which the ashes became entangled in the complicated manner we find upon Break-heart Hill.

The banding so well marked in the felsites upon the western shore of Marblehead Neck until quite recently has been considered stratification, and therefore appeared to be a fatal argument against the theory of those who regard the felsites as exotic. Dr. Wadsworth was the first to consider the banding a fluidal structure, equivalent to that so prominent in the modern rhyolites, and consequently of igneous origin. It is of common occurrence, especially in the silicious felsites of Lynn, Saugus, and Melrose; and from the fact that where it is found in felsite, forming distinct dikes or tongues in the granite, or enveloping fragments of other rocks, the banding is parallel to the line of contact, there seems to be no good reason for doubting that it was produced by the flowing of the felsitic matter in a state of fusion. The extreme complexity of the banding upon Break-heart Hill and at places in Marblehead Neck cannot be satisfactorily explained by any other supposition, and it is scarcely necessary to add that under the microscope the phenomena of the banding are wholly at variance with those found in sedimentary rocks and completely in harmony with those of altered rhyolites. The banding, therefore, instead of furnishing an argument in favor of the sedimentary origin of the felsites, is proof of their eruptive character.

Since the relation of the felsite and granite has been the subject of such discrepant statements, we shall point out the localities in which, as it seems to us, the relation is clearly exposed. Within the granite southwest of Spot Pond a dike of somewhat pinkish felsite occurs near the top of a high hill west of the north end of Brooks's Lane, where it enters Forest Street. Further northward and nearer to Forest Street there are at least half a dozen smaller dikes of a similar felsite in the granite. That these masses of felsite are true dikes and not included fragments within the granite is proved by the fact that they not only send irregular tongues of felsite from the main dike into the adjoining rock, but also that they hold within themselves detached fragments of the granite which they penetrate. The small patch of granite northeast of Prospect Hill, Malden, is penetrated by one of the largest felsitic dikes of this region. It may be seen in the cliff directly opposite Faulkner's station. Along the Newburyport turnpike in Malden there is a small area of granite to which we have elsewhere * alluded. Mr. Crosby † regards this rock as granitoid petrosilex. We placed it among the granites not only on account of its granitic structure, but from the fact that it is clearly distinct from the adjoining felsite. In a gravel-pit upon the east side of the turnpike, a short distance north from Salem Street, several junctions of the granite and felsite may be seen. The felsite is in some places slightly banded along the contact, and the line of junction between the two rocks can be readily traced from the south part of the gravel-pit for a considerable distance over the hills to the eastward. Passing a short distance northward along the turnpike several low cliffs appear upon the left. In the second of these, two well-marked dikes of reddish felsite occur. One of them is about five feet in width, the other about twelve feet, and they cut through an almost vertical cliff of the granite twenty-five feet in height. These dikes may be traced at intervals for nearly a quarter of a mile to the northeast. The granitic rock of this area, as well as that northeast of Prospect Hill, is quite different in its general aspect from the granite of the larger areas to the northward; but, so far as the facts are known, there seems to be no good reason for supposing that it is not granite, or that its relation to the felsite is different from that of the other granites.

The large granitic mass extending from eastern Melrose into central and northern Saugus is bounded upon the south and east and partly upon the west by felsite, so we would expect to find within this area numerous exposures of the two rocks in contact, and thereby determine their relations. Near the eastern end of Long Pond in Saugus there are several distinct dikes of felsite in the same granite which at the west end of the pond, about one fourth of a mile distant, as already mentioned, contains well-marked inclusions of the stratified group. One of the most distinctly marked dikes may be found upon the eastern end of the granite hill north of Essex Street, about a quarter of a mile northwest from the Newburyport turnpike. The strike of the dike is N. 20° E., and it varies, within a distance of sixty feet, from six to ten feet in width.

The most interesting and instructive exposures of the stratified group,

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* Proc. Bost. Soc. Nat. Hist., Vol. XX., p. 357.

† Contributions to the Geology of Eastern Massachusetts, p. 78.

granite and felsite near together, are to be found upon Break-heart Hill in Saugus. It is to this locality that Mr. Crosby refers when he says: * "On the high hills to the west of the private road running from Forest Street and Central Brook to Water Street we have, perhaps, the finest example of the extravasation of the granite yet observed in this region. The exposures of the rock here are remarkably good; and the granite is coarse and sharply defined where it penetrates the adjoining petrosilex and hornblende slate in irregular dykes, or envelops isolated masses of these rocks that have been wrested from the parent beds."

Concerning the fact that the granite envelops detached fragments of the stratified group there can be no doubt; but when we come to examine the relations of the felsite and the granite, the evidence is not so easily deciphered. The top of the hill is composed of a mixture of felsite and volcanic ashes, which extends over the southeastern slope, meeting the rocks of the stratified group; to the northward, a short distance, this mixed mass is limited by the coarsely crystalline granite containing the stratified fragments; and to the westward it connects with a large area of similar rocks forming the high hills near by in that direction. Within the small area of this complex rock there are two patches of granite. One of these, with a diameter of about twenty-five feet, upon the western brow of the hill, has its side penetrated by a tongue, at least six feet in length, of very distinctly banded felsite. The banding is also very distinctly marked at several places along the periphery of the granite, and in every case it is parallel to the line of contact between the two rocks. The smaller patch of granite upon the southern slope of the hill is completely enveloped by felsite. Although the felsite in this case is not banded, it apparently sends tongues into the granite, and, near the junction of the two rocks, it envelops small fragments of the larger mass which it surrounds. Although there are other exposed contacts of the felsite and granite in the neighborhood, none were observed to furnish important evidence bearing upon the relations of the two rocks. The banding of the felsite is undoubtedly of igneous origin, and its occurrence about the granite, together with the tongues of felsite penetrating the granite, and fragments of the latter rock enveloped by the former, are phenomena which, as it seems to us, can be explained only by supposing that the felsite flowed through and around the granite.

The well-marked dikes of felsite cutting the granite between Fishing Point and Phillips Beach on the Swampscott coast, as first pointed out

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* Contributions to the Geology of Eastern Massachusetts, p. 78.

by Dr. Wadsworth, as well as the numerous examples found upon the coast of Marblehead Neck, conclude an array of facts which establish, beyond dispute, not only that the felsite is a truly eruptive rock, but also that in every case where we could determine its relation it is younger than the granite which it penetrates.

The relation of the felsite to the stratified group is the subject of very different opinions, and for this reason it seems proper to present in detail the evidence we have observed bearing upon this question. If the phenomena described sustain the conclusions already drawn, viz. that the stratified rocks of Medford, Stoneham, Melrose, and Saugus are older than the eruptive granites of that region, and that the felsite is a truly eruptive rock younger than the granites, it is evident that there can be no gradual passage from the felsite into the stratified group.

Mr. Crosby,* who has done so much on the geology of Eastern Massachusetts, refers to the region west of the Boston and Maine Railroad in Melrose as the one which "places beyond question the fact that there is a gradual transition between the quartzite and petrosilex, and that portions of the latter rock are intercalated in the stratified group." This group is well exposed near the railroad, a short distance south of the Melrose station, and extends southwestward, parallel with the general strike of the formation, across Spot Pond into Medford. Excellent outcrops, perhaps the best of the stratified group in this region, form a part of the northern shore of the pond. The felsites and stratified rocks are exposed within several hundred yards of each other upon opposite sides of Washington Street, Melrose, a short distance east of the Melrose-Stoneham line. The exposures in both cases are within the regions marked felsite by Mr. Crosby. Those upon the north side of Washington Street are distinctly sedimentary rocks, while the rocks in the cliffs to the southward are well-marked felsite, slightly porphyritic, of the kind forming the mass of the Malden Highlands. Although I have examined several times the region between Spot Pond and Long Pond, where the stratified group meets the felsite to the southward, I have not been able to find the two rocks in place exposed nearer to each other than at the locality described; and although in the present state of our knowledge the existence of a "gradual transition" or intercalated felsite in the stratified group cannot be denied, it may be stated that careful search has not revealed to us the slightest evidence in favor of Mr. Crosby's positive assertion. It is hoped that the exposures which place such an important fact beyond question will be described in detail, so that other observers may obtain the evidence.

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* Contributions to the Geology of Eastern Massachusetts, p. 106.

Fortunately we need not depend for a knowledge of the relations of the rocks in question upon a region in which the absence of exposures along the line of contact renders it difficult to tell what may be true. Upon the northern boundary of the stratified group, from Break-heart Hill westward towards Main Street, the relations of the rocks are clearly exposed. Between Break-heart Hill and Main Street several distinct contacts of the felsite and quartzite may be seen, and there are no indications whatever of a transition between the two rocks. It will be remembered that, in describing Break-heart Hill, it was mentioned that the complex mixture of felsite and ashes extends from the summit down the southeastern slope to the rocks of the stratified group. Near the middle of the slope facing Mr. Edmond's house is a small ledge, furnishing an excellent exposure in which the felsite, with contorted banding, overlies unconformably at a large angle the upturned edges of the stratified group. The rocks beneath are in part quartzite interstratified with other rocks of the same group, and the line of contact sloping down the hill is well marked. A short distance to the eastward the banding in the felsite and the distribution of the ashy material has the same general slope as the plane of contact.

It seems to us that this very interesting exposure places beyond the possibility of a doubt the conclusion that the felsite is younger than the rocks upon which it reposes. A few rods to the southwest of the exposure just noticed there is another, which shows apparently one side of a dike of felsite cutting through the stratified rocks. The line of contact is very distinctly marked and irregular, like that of an eruptive rock, and is at right angles to the bedding of the adjoining rocks. Distinct fragments of quartzite belonging to the stratified group are enveloped by the felsite of this locality, and small ones have been found embedded in the ashes.

The facts observed upon Break-heart Hill are in harmony with the relative positions of the two rocks as determined by the relations of both to the granite, and there appears to be no doubt that the stratified rocks of Melrose and the adjoining towns are older than either the granite or felsite.

Having considered the relations of the older rocks to the felsites, let us turn our attention to the relations which the felsites hold to one another. Mr. Crosby has shown that the rocks of the group vary widely in chemical composition, and Dr. Wadsworth has called attention to the fact that upon Marblehead Neck the felsites are not all of the same age.

The stratified group which we have already described separates the adjoining felsites into two distinct areas, each of which includes several felsites of different periods of eruption. The felsite which is so intimately associated with the ashes upon Break-heart Hill occupies a considerable portion of the area east of Main Street, and between Break-heart and Little Castle Hills. A junction between the dark-colored felsite and a pale pink felsite may be traced across the northern part of Little Castle Hill, and southwest of this hill, about half-way to Main Street, another distinct junction occurs along which there is very well marked banding in the light-colored felsite, showing that it is the younger. Neither of these felsites is very porphyritic.

Within the southern area, a short distance southeast of Long Pond, Saugus, there is a small patch of a red, chiefly non-porphyritic felsite. The region immediately south of the pond, and to the southwest as far as the Boston and Maine Railroad, is occupied by a felsite which is generally very porphyritic. The ground-mass of this felsite varies somewhat in color, but it is usually light pink or pale purple, and besides being the most completely and uniformly porphyritic felsite of this region, very frequently envelops fragments of older rocks. It might properly be designated the porphyritic, pebble-bearing felsite, for these two features are comparatively uniform throughout the wide area occupied by this beautiful rock. The red non-porphyritic felsite, to which we have already referred, forms a very clearly marked junction with the porphyritic felsite about one fourth of a mile southeast of the eastern end of Long Pond, and the porphyritic felsite, which is distinctly banded along the line of contact, penetrates the adjoining red felsite, and envelops many of its fragments. Among the enveloped fragments in the porphyritic felsite are found a few of granite, — a fact which accords with those we have already discussed in showing that the granites are older than the felsites. The pebbles of the old felsite are numerous and widely distributed in the porphyritic felsite, and the evidence is so complete and well marked, that, as it seems to us, there can be no doubt that the two felsites were extruded at different periods.

About a third of a mile southeast of Swain's Pond in Melrose the porphyritic felsite is cut by a dike of what appears to be a third felsite, which is non-porphyritic and of a gray color. The dike has very irregular junctions, varies in width from a foot to eighteen inches, and can be traced across an exposure for a distance of thirty feet. The youngest of the felsites does not appear to have a very extensive development in that region.

Within the felsites many junctions of apparently different rocks may be seen; but because, as it appears to us, it may be possible for different parts of the same eruptive mass to form distinct junctions with each other, we were not inclined to accept junctions alone as evidence of difference in age unless supported by other facts. It appears to be evident, however, that not only at Marblehead Neck, as shown by Dr. Wadsworth, but also in each of the two areas of felsite we have explored, there were at least two distinct eruptions of felsite.

That some of the felsites are distinct in age is clearly shown also by their relations to the fragmental rocks, the so-called breccias, with which they are associated; but these relations can be considered to better advantage after the latter rocks have been described.

Fragmental Rocks.

The complex group of rocks included under the above name embraces those commonly called breccias in this vicinity, and is composed of members wholly distinct in origin and composition. The coarse fragmental rocks, whose fragments may be either angular or well rounded, are perhaps more abundant than the sandstone and finer-grained rocks. Most of these rocks are composed of fragments of highly altered igneous rocks, the felsites and granites, and properly belong to the tufas, or, according to Dr. Wadsworth's classification,* the porodites. There are, however, a number of localities where the conglomerate is composed chiefly of pebbles of quartzite from the stratified group.

The volcanic ashes to which we have already referred as occurring in the neighborhood of Break-heart Hill are undoubtedly of igneous origin, but in other regions the material is distinctly stratified, and must have been produced by aqueous agencies. Although we have no evidence which proves certainly the relative age of the ashes, it seems probable, from the fact that they are so intimately mixed with the oldest felsite, that they were produced about the same time with the felsite, and earlier than the stratified porodites (tufas) and conglomerates. It is sometimes extremely difficult to distinguish in the field between a recomposed rock and an eruptive one which has, at the time of its extrusion, picked up many fragments.† Only those exposures which are quite certainly of sedimentary origin will be noticed; although they are quite numerous, they are comparatively small. Mr. Crosby was the first to notice the stratification of these rocks, and pointed out the locality at Dungeon Rock, Lynn, where the material is fine, and apparently all derived from the felsites. Another similar locality in which the stratification is well marked occurs along the water-pipe between the reservoir and the water-works, Lynn. In these areas it is almost impossible to tell, upon a weathered surface, that the rock is fragmental. These exposures were accidentally brought to light by quite extensive excavations, and it is possible that some of what is now regarded as felsite may be a recomposed rock, so like felsite (from which it was made) in its external appearance as not to be distinguished from it by the unaided eye. The area of porodites and conglomerates of Vinegar Hill and Pirates' Glen is probably the largest area of these rocks in this region. In the same locality there are several small patches of granite mixed with the fragmental rocks which are in places distinctly stratified.

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* Bulletin of the Mus. Comp. Zoöl., Cambridge, Mass., Vol. V., No. 13, p. 280.

† See paper by the writer. Proc. B. S. N. H., Vol. XX. 355.

One of the most interesting exposures of the stratified porodites is upon a high hill, a short distance south from Saugus, and near the east side of the road leading to Sweetser's Corner. The greater portion of the hill is felsite, but upon its northern slope occurs the most beautiful coarse tufa of this region. It is tilted so as to be standing nearly or quite vertical, with a strike N. 70° E. At this place the thickness, measured directly across the strike, is about 150 feet, and may be greater, but for want of exposures the excess beyond 150 feet cannot be determined. This is the only locality we have found to furnish an opportunity to determine the thickness of the fragmental rocks.

An exceptional conglomerate occurs a short distance west of the Saugus station, near the railroad. Its peculiarity consists in its association with the granite, and that it is composed almost wholly of granitic débris. Some of the pebbles are large and well rounded, and the mass seems to lie directly upon the rocks from which it was derived. An unsuccessful attempt has been made to use this material for the bases of gravestones.

Between Cliftondale station and the Newburyport turnpike there is quite a large area of conglomerate containing a considerable proportion of quartzite pebbles. A smaller area of finer material occurs near the end of Granite Street, by the spring, about a third of a mile north of Maplewood.

A most interesting and varied locality in which the stratification is well marked may be found about a third of a mile southeast of Swain's

Pond in Melrose. Although the locality is small, it embraces a variety of fine-grained, red, argillaceous rocks, sandstones, and a very coarse conglomerate composed almost wholly of pebbles of quartzite from the stratified group.

In the base of a small hill a short distance northeast of Oak Grove station, on the Boston and Maine Railroad, the fragmental rocks of this group are well exposed. They extend into the base of Prospect Hill, and on the opposite side of the valley are exposed near the base of the Malden Highlands. Within the Highlands there are two small areas of tufas, one on each side of Highland Avenue along the Malden-Medford line. The conglomerate of West Medford, which is well developed along Purchase and Mystic Streets, resembles to a considerable extent some parts of the Roxbury conglomerate; but Mr. Crosby is most likely correct in connecting it with the fragmental rocks so intimately associated with the felsite.

Within the felsites north of the stratified group we have found only two small areas which, as it seems to us, are of sedimentary origin. One of the patches lies upon the first hill north of Oak Street, a short distance west of Nahant Street (Main Street), Wakefield, and the other is upon Candle-wood Hill, northeast of the Stoneham station on the Boston and Maine Railroad. It is very probable that a number of areas of sedimentary rocks have escaped our notice, but we feel sure they do not occupy the large areas over which they have been represented to extend. The very porphyritic felsite occupying the region lying between Long Pond, Saugus, and the Malden Highlands contains, as we have already stated, many pebbles of other felsites, and some of granite, but, like that at Red Rock, Lynn, it is by no means of sedimentary origin.

We have elsewhere * shown that some of the felsites are younger than the fragmental rocks so intimately associated with them, and it remains in this connection to point out the facts upon which this inference is based.

In the conglomerate about a fourth of a mile north of Cliftondale station there is a dike of pinkish felsite which is clearly eruptive through the fragmental rocks of the same locality. A similar phenomenon may be seen north of Oak Street, Wakefield, where a distinct tongue from the black-edged dike penetrates the adjoining fragmental rocks. The best locality, however, for observing the relations of these rocks is southeast of Swain's Pond, where the porphyritic felsite not only penetrates in the form of small, irregular dikes the fragmental rocks, but

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* Proc. Bost. Soc. Nat. Hist., Vol. XX., p. 364.

also in one exposure distinctly overlies them. This relation enables us to understand how it happened that the coarse quartzose conglomerate is completely surrounded by felsite which does not appear to have entered into its composition. The porphyritic felsite being younger than the fragmental rocks, it is not difficult to explain the fact that it contains so many pebbles. In Prospect Hill, Malden, and the small hill near by, just northeast of the Oak Grove station, the porphyritic felsite apparently overlies the fragmental rocks of the same locality. The dark-colored, less porphyritic felsite of the Malden Highlands is closely related to the porphyritic one to the eastward, and there is good reason to believe that the former, like the latter, is younger than the tufas of that region. The tufaceous rocks along the Malden-Medford line north of Highland Avenue are composed almost wholly of very silicious felsites, unlike those by which the small area is completely surrounded; a fact which, as it seems to us, can be explained most satisfactorily by supposing that the dark felsite of the Highlands had not been spread upon the surface in its present position at the time the fragmental rocks were formed. The evidence we have given seems to us sufficient to fully establish the conclusion that some of the felsites are younger than the fragmental rocks with which they are intimately associated; and on the other hand, it cannot be doubted that these fragmental rocks are more recent than the felsites of whose débris they are largely composed.

Diorite.

The diorite adjoins the felsite for only a few miles along the northwestern boundary of the latter, between Melrose Highlands and Smith's Pond (Crystal Lake), Wakefield. The line of contact is generally covered, and the two rocks were not seen upon the same exposure north of West Hill, near the Stoneham station * on the Boston and Maine Railroad. Upon this interesting hill we find a complex mixture of almost all the rocks of the region, and it appears to us that the diorite penetrates and envelops not only the stratified group, but also the granite and felsite. Distinct fragments of the granite and felsite have been seen in the diorite at several places. Similar phenomena may be seen upon the hills in Stoneham, near the south side of Franklin Street, where the eruptive diorite penetrates the granite, and cuts directly across the bedding of the stratified quartzites and schists. In that region the granites, diorites, and rocks of the stratified group are intermingled

* The name of the post-office at Stoneham station is Melrose Highlands.

in a very complicated manner, but we have not been able to find any evidence which would lead us to suppose that there is a gradual transition from any one of the rocks into another of the same locality. It seems evident to us that the diorites are truly eruptive rocks, and that their extrusion has taken place since that of the granite and felsite which they penetrate.

Diabase and melaphyr, so abundant in the neighborhood of Boston, are found in very distinct dikes, cutting all the other rocks, and close the series of eruptive rocks in which there seems to have been, in the order of extrusion, a general progress from silicious to basic rocks.

The relative ages of the rocks in the region we have explored, as it seems to us, have been pretty clearly established, but the position of the whole series in the geological column is a matter concerning which we have seen very meagre and conflicting evidence. The slates, supposed by some to be primordial, lying between the Charles River and the hills of Medford and Malden, have not been found, so far as we know, in contact with the eruptive rocks to the northward. On the north side of the Saugus branch of the Eastern Railroad, between Faulkner's station and Maplewood, the slates are exposed within about one hundred and fifty feet of the hills of eruptive rocks upon the north side of Salem Street. The slates dip steeply (66°) to the northward, as though they were plunging beneath the other rocks. It may have been this fact which led Prof. John W. Webster, many years ago, to assert that the transition rocks (slates, etc.) were overlain by the porphyries of Malden.

In the rocks of the stratified group, so far as we know, fossils have never been found; and were it not for the fact that the Roxbury conglomerate contains numerous pebbles of quartzite, apparently derived, at least in part, from the rocks of the stratified group, I can see no good reason for supposing the stratified group to be pre-palæozoic. The same conglomerate contains pebbles of felsite, but whether any of them are from the felsites now exposed along the northern margin of the Boston basin is a question which, for its satisfactory solution, will require much more thorough and careful work than has yet been done in this region.

Conclusions.

The facts we have observed in the region described in the foregoing paper appear to establish, for that region, the following conclusions: —

The stratified group contains the oldest rocks of which we have any knowledge in that region, and, before the extrusion of the more recent eruptive rocks, they probably had a much wider distribution upon the surface than they now have.

The granites are not derived by metamorphism from any part of the series of rocks (stratified group) which they envelop, but are truly eruptive rocks, whose extrusion has occurred since the formation of the stratified group. Therefore the granites, as we know them in their present position, are younger than the stratified group.

The felsites are eruptive rocks, more recent than the granites. There were at least two eruptions of felsite in each area, and in the southern area there were probably three eruptions.

The fragmental material associated with the felsite upon Break-heart Hill is a volcanic ash; elsewhere the fragmental rocks have generally been formed of material eroded and deposited by water.

The very porphyritic felsite between Long Pond and Prospect Hill, part of the felsite of Wakefield and at Cliftondale, and probably the dark-colored felsite of the Malden Highlands, are younger than the tufas and conglomerates with which they are associated.

The diorites are eruptive, and younger than the felsites.

The diabases and melaphyres are the youngest eruptive rocks of this region, and there has been, in the order of eruption beginning with the granites, a general progress from silicious to basic rocks.

No. 3. — *On an Occurrence of Gold in Maine.* *By* M. E. Wadsworth.

The gold under consideration here is found on Seward's Island, a small island in the town of Sullivan, Hancock County. The gold is found in quartz veins cutting an eruptive mass of diabase. This diabase forms a dike of about 40 feet in thickness, lying approximately parallel to the bedding of an indurated fine-grained argillaceous mica schist; all dipping nearly S. 30° W., 24° to 42°. The dip averages about 35°, and the strike is far from being uniform. Crossing the diabase at various angles, but generally from north to south, are segregated quartz veins. In some places the rock is a confused reticulated mass of these veins, with patches of diabase lying between them. The veins vary in width from a mere seam to even a foot in breadth. Starting where only one or a few of them are visible, they gradually increase in number until they become quite numerous, while they will doubtless be found to fade away as they began. The diabase and schists are cut by several dikes of diabase running approximately at right angles to the strike of the schist, or parallel to the veins. The vein stone is quartz, together with some calcite, tremolite, and chlorite, and carries tetradymite and gold.

So far as examination has been made, the veins in the diabase carry gold, and the decomposed diabase immediately adjacent to the quartz veins also contains that metal to a greater or less extent. The gold occurs principally in small grains in the vein in connection with the tetradymite, bits of decomposed diabase, and in the cavernous portions, but not in the compact quartz of the vein itself. The tetradymite is in irregular grains and masses, showing a brilliant metallic lustre and a well-marked basal cleavage. The locality is worked for its gold, and was visited by the writer in December last.

Cambridge, Mass., January, 1881.

No. 4. — *A Microscopical Study of the Iron Ore, or Peridotite, of Iron Mine Hill, Cumberland, Rhode Island. By* M. E. WADSWORTH.

THE attention of the writer was first particularly called to this formation by some specimens presented to him by Mr. H. B. Metcalf in the spring of 1880. These did not appear to the writer to be any common ore of iron, but rather fragments of a basic eruptive rock containing much iron. Sections were accordingly made which revealed its true character.

The formation was described by Dr. Charles T. Jackson in his report on the Geological Survey of Rhode Island in 1840. He states that Iron Mine Hill "is a mountain mass of porphyritic magnetic iron ore, 462 feet in length, 132 feet in width, and 104 feet in height above the adjoining meadow. From these measurements, which were made over only the visible portion of this enormous mass of iron ore, it will appear that there are 6,342,336 cubic feet of the ore above natural drainage. . . . Its specific gravity is from 3.82 to 3.88. . . . This ore is remarkable both on account of its geological situation and its mineralogical and chemical composition. It appears to have been protruded through the granite and gneiss at the same epoch with the elevation of numerous serpentine veins which occur in this vicinity. This will appear the more probable origin of this mass, when we consider its chemical composition in comparison with that of the iron ore, which we know to have been thrown up with the serpentine, occurring on the estate of Mr. Whipple, and the fact that the ore at Iron Mine Hill is accompanied by serpentine mixed with its mass in every part, gives still greater reason for this belief." (*l. c.*, pp. 52, 53.)

He gives as the result of his chemical analysis of the "Porphyritic Iron Ore from Iron Mine Hill, Cumberland," the following (*l. c.*, p. 53): –

SiO_2	23.00
Al_2O_3	13.10
Fe_2O_3	27.60
FeO	12.40
MnO	2.00
MgO	4.00
TiO_2	15.30
H_2O and loss	2.60
Total,	100.00

In 1869 the Rhode Island Society for the Encouragement of Domestic Industry published a report relating to the coal and iron in Rhode Island, from which we glean the following. The iron ore is regarded as practically inexhaustible, the mass at Iron Mine Hill visible above drainage being estimated at two millions of tons.

"It is also conceded, as regards quality, that the Cumberland ore is free from sulphur and phosphorus, the most common and worst impurities, and that it contains manganese, the most prized of all the elements found in connection with iron. For these reasons the Cumberland ore is sought by manufacturers at a distance, to mix with softer ores and improve their quality, and is now exported from this State for that purpose."

It seems that this Iron Mine Hill ore was employed in 1703, mixed with the hematite of Cranston, R. I., for the casting of cannon. The work was done at Cumberland, and, in part at least, "the cannon used in the celebrated Louisburg expedition, in 1745," were cast from these ores. The manufacture was abandoned in 1763, owing to an explosion of the furnace, by which the proprietor was killed.

During the administration of John Adams the same ores were also used for the manufacture of cannon. It seems that the Cumberland (Iron Mine Hill) ore was employed in the manufacture of charcoal iron at Easton, Chelmsford, and Walpole, Mass., as late as 1834. "The Cumberland ore, mixed with equal quantities of Cranston hematite or bog ore, produced, for a long period, a charcoal iron unsurpassed in this country. . . . The Cumberland ore contains an uncertain percentage of titanium, which, while it improves its quality, helps make it refractory. The ore is porphyritic, the magnetic oxide being associated with earthy minerals, principally feldspar and serpentine." It would seem that in 1869, and before, the ore was largely shipped to Pennsylvania to mix with other ores.

A letter of Professor R. H. Thurston, published in this report, states: "The Cumberland iron ore is of the kind known to mineralogists as 'ilmenite'; among metallurgists as 'titaniferous magnetic ore,' and iron manufacturers, on account of its peculiar value for producing steel, would term it a 'steel ore.' . . . The Cumberland ore is conveniently located and of inexhaustible extent; it is perfectly free from noxious elements, though somewhat refractory; it will furnish a very strong iron or a most excellent steel; it can be smelted within the State at a profit; it can be made directly into steel at a much greater profit; steel made from it will bring the highest prices in the market."

Professor Thurston states that the mean of various analyses made of this ore is about as follows: —

SiO_2	22.87
Al_2O_3	10.64
Fe^2O^3 FeO	44.88
MnO	2.05
CaO	0.65
MgO	5.67
TiO	9.99
Zn	0.20
H_2O and loss	3.05
Total	100.00

The ore on one side of the hill, where it has been most extensively quarried, shows a dark, somewhat resinous groundmass, holding large striated crystals of feldspar. The resinous lustre and greenish-yellow color, as observed under the lens, are caused by the presence of olivine. The olivine becomes more strongly marked on the slightly weathered surfaces seen on the faces of the quarry. Under a lens of high power, the olivine shows clearly on the fresh fractures. The olivine in weathering decomposes to a yellowish and reddish-brown ferruginous powder, leaving the other constituent of the rock, the magnetite, well marked. The magnetite decomposes more slowly, and forms an incoherent mass after the decay of the olivine. The rock gelatinizes with hydrochloric acid, and yields a titanium reaction. A fragment allowed to stand a day or two in weak hydrochloric acid yielded gelatinous silica copiously.

A section made with special reference to the feldspar crystals shows large porphyritic crystals of the latter enclosed in a mass of magnetite and olivine.

The magnetite forms irregular, more or less connected masses, making a sort of sponge-like structure. Its rounded and irregular cavities are filled with olivine, which also occupies the interspaces between the magnetite masses. The olivine is in rounded forms, which sometimes show one or more crystal planes. It is cut through by numerous fissures, that usually show a ferruginous staining along their sides. The olivine also holds grains of the magnetite. Except the fissuring and ferruginous staining, the olivine is comparatively clear, and shows little signs of alteration.

The plagioclase feldspar shows well-marked lines of cleavage and fracture, and is somewhat kaolinized along these lines. It contains a few irregular flakes of biotite together with grains of olivine and magnetite.

The order of crystallization appears to have been, first the magnetite, then the olivine, and lastly the feldspar.

This rock is similar to the celebrated iron ore of Taberg, Sweden, as described by A. Sjören in the Geologiska Föreningens Forhandlingar (1876, III. 42 – 62; see also Neues Jahrbuch für Mineralogie, 1876, 434, 435). The Taberg rock has been worked as an iron ore for over three hundred years. This Swedish ore is called by Sjören "magnetite-olivinite."

The feldspar is confined to the peridotite found on one side of the hill, where the peridotite passes into a compact greenish-black rock, showing patches of serpentine and grains of magnetite. From this fact it seems necessary to regard the feldspar as abnormal and local in the rock, which in general is composed of olivine and magnetite or their alteration products.

The structure remains about the same in the non-feldspathic portions as it is in those before mentioned as holding feldspar. But the olivine is entirely changed to a greenish serpentine which shows beautiful fibrous polarization. The serpentine retains the form of the olivine grains, their inclusions, and the network of fissures before mentioned. In some of the sections considerable carbonate was seen, presumably dolomite. In one section part of the olivine grains, especially towards their interior, remained unchanged, but on their edges they were altered to serpentine. Another change was observed here: the formation of secondary crystals of irregular outline that belong probably to actinolite. Some are elongated and narrow; others are short and broad, traversed by cleavage planes. They evidently belong to the monoclinic system.

The origin of this rock could not be told from its field relations, as its contact with any other rock could not be found. Since the only method in which its origin can be absolutely shown cannot be used without expensive excavation, it only remains to give the probabilities so far as ascertainable from the mass itself. Such microscopic characters and mineral association have been, so far as we know, only found in eruptive rocks when the origin of such rocks has been studied with sufficient care to determine it. Hence we must conclude it is most probable that this mass is eruptive also, until found to be otherwise.

It closely resembles in structure and composition some of the meteorites, except that its iron is oxidized and not in a native state, — a resemblance which for others of the peridotites has long been pointed out.

It is rocks of this character, as has been suggested by others, that give us the most probable clew to the interior composition and structure of the earth.

The rock in the field shows, to our mind, no signs of structural planes that should be referred to sedimentation. On one side the rock is massive and jointed, and on the other it is jointed in fine parallel planes. This portion of the rock is more highly metamorphosed than the other, and, as is usual in highly altered eruptive rocks, joints parallel to certain lines of pressure occur. The writer has seen this structure in many rocks that were indisputably eruptive, forming well-marked dikes in other rocks.

A rod away from the main mass of the iron ore, near one end, some serpentine appears that cannot be directly connected with the other peridotite. Microscopically its characters and structure are the same as the main rock, and there is no reason to regard it as distinct. The rock nearest to the peridotite is a mica schist some hundred feet away. It shows no characters that would indicate the transition of the ore into it.

The locality was visited by the writer in October last, in company with Professor A. S. Packard, Jr., of Brown University, and Mr. T. S. Battey, of the Friends' School, Providence, R. I. To the latter gentleman I am especially indebted for a copy of the paper of the Rhode Island Society before mentioned, and for other favors.

This examination may serve as an illustration of the aid that microscopical lithology may be to the practical side of life, since now, for the first time since this rock has been worked, can the ironmaster who wishes to use it approach understandingly the metallurgical problems it presents; whether he desires to employ the rock as a whole, or to concentrate the magnetite first.

Cambridge, Mass., May 13, 1881.

No. 5.—*Observations upon the Physical Geography and Geology of Mount Ktaadn and the Adjacent District.* By C. E. HAMLIN.

THE "Geological Map of Northern Maine," that accompanies the "Preliminary Report upon the Natural History and Geology of the State of Maine," for 1861, represents Mount Ktaadn* as included in a large granite district, of which it is the culminating height. The area, as delineated, is an ellipse, the axes being respectively about twenty and forty miles in length, — the major axis running very nearly in a northeast and southwest direction. Between the most northerly of the two foci and the northeast border of the district, Ktaadn is placed; while between the other focus and the southeast margin are situated the "Ebeme Mountains," so called by the compiler of the map. The Penobscot River, in a course intermediate with the two axes and oblique to each, crosses the intervening country, which has a general elevation of not more than 550 feet above sea level, and is thickly sown with lakes.

An excursion, of which this paper states results, was made in August last, along a route that passes through nearly the whole length of the supposed granite area. The special purpose of the writer at the outset was to compare the granite of the lower grounds with that of Ktaadn itself, which had been partially studied in August, 1879, and less carefully in 1869 and 1871; to find, if possible, at some points, the junction of the granite with the surrounding stratified rocks; and to continue the exploration of Ktaadn with reference to completing the model of the mountain, of which a heliotype is herewith presented. The route selected comprises the northern seven miles of Schoodic Lake, fifteen miles of forest travel to the Middle Joe Merry Lake, a course through this, the Lower Joe Merry, Pemadumcook, and Ambejijis Lakes and their connecting "throughfares," and nine miles up the Penobscot to the mouth of the Aboljacarmegus Stream, where the ascent of Ktaadn begins. From the terminus of highways at Brownsville, the route measures about fifty miles in length.

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* The spelling *Ktaadn* is adopted in accordance with an opinion communicated to the writer by J. Hammond Trumbull, of Hartford, the most eminent living authority upon Indian dialects. Dr. Jackson, Thoreau, and a few others, have previously used the same form.

As almost nothing definite is on record respecting the depths of the lakes that cover so large a portion of Northern Maine and British America, soundings as numerous as circumstances permitted were made of the lakes traversed. And though the Geological Reports represent the lakes above named — except the first, of which no account has appeared in print — as enclosed by shores made up of loose material, it was thought best, in consideration of the remarkably low stage of water then prevailing, to re-examine the shores and beds of the lakes in regard to their composition. The same course was adopted for the Penobscot River, especially at the five falls and portages that intervene between Ambejijis Lake and Aboljacarmegus Stream.

The Lakes.

Schoodic* Lake, which shares its name with the larger Schoodic lakes that lie on the eastern border of Maine, is in some respects the most interesting of all that occur in this region. In his "Water Power of Maine," Wells gives its area as sixteen square miles, and it is said to have a length of ten miles, and in its central part to be two and a half miles wide. It is free from islands, except at a single point upon the eastern shore; and the forest that surrounds it shows no break in its continuity, nor any other sign of settlement. The absence of islands from the main body of the lake indicated deep water; but the rough condition of the surface, when we boated over it, prevented us from trying the depth. Our guide, Mr. Clapp, was employed to sound the lake on his return, and the list of his numerous and careful soundings shows it to be by far the deepest of all the lakes through which our route lay. The part over which we passed is enclosed by shores of granitic detritus, and there was nowhere to be seen any outcrop of the slates that underlie the whole surrounding district.

From the Schoodic to the Middle Joe Merry, our way was along a logger's road through continuous forest, which occupies a land surface very level and entirely drift-covered, not one exposure of ledge being observed in the whole distance of fifteen miles. Since our course through the series of lakes will be apparent from inspection of the accompanying map, no more need be said of it than that, favored in general by absence of wind, which, in a brief space of time, raises on these lakes a sea dangerous to boats, our examinations were continued from Pemadumcook Lake to the foot of the North Twin, whence, returning to Ambejijis Lake, we proceeded up the Penobscot.

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* The name as applied to this lake is probably a refinement upon an earlier one, found on the older maps, that of *Skootum* Pond, itself perhaps the corruption of some now unknown Indian name.

For the first ten days our party consisted of six persons, two boats' crews; — one made up of my companion in two former trips to Ktaadn, Dr. Crosby, of Waterville, Me., his son and nephew; the other, of Mr. L. E. Blake, of Worcester, Mr. Clapp, and myself. In sounding lengthwise of the lakes, our boats often took opposite sides, and, landing frequently upon the shores and islands, we carefully viewed the unusually wide extent of rocky surface laid bare through the long-continued drought. Very nearly the same conditions observed in one were found to prevail in all the other lakes and their connecting streams. All are bordered by detrital deposits, constituting occasional sandy or pebbly beaches of small extent, but ordinarily made up of granite bowlders having angles but little rounded by attrition, and which are often so crowded together as to resemble walls. The smaller islands that stud the lakes are sometimes banked up on all sides, or wholly covered over, with bowlders that have been borne to their present resting-places by the action of ice in successive winters.

The only occurrence of rock in place, upon any of the lakes and throughfares visited, was observed later upon the Upper Joe Merry, which lay to the west of our route from Schoodic Lake to the Middle Joe Merry. On the return of Dr. Crosby and his companions, at the end of ten days, they "carried" from the Middle to the Upper Joe Merry, which has a length of about three miles. An examination of its margin, made at my request since I was myself to return from Ktaadn by the Aroostook route, discovered upon a projecting point a granite ledge, which for seventy-five feet forms the shore, rising steep ten feet from the water. The southern half of the lake was crossed, but, with the exception named, only shores of drift were seen. Soundings were at the same time taken, which will be given in the tables of depths.

Ambejijis Lake, uppermost of the series of expansions of the Penobscot known as the Pemadumcook chain of lakes, and but two miles long by three fourths of a mile wide, receiving directly whatever of detritus is swept down by the rapid river above, might be expected to be shallower than the rest. It proved, however, to be deeper than the average of the others, and here at one place was made the deepest sounding, 51½ feet, that occurred in the series. This lake was once a connecting link between Pemadumcook and the larger Millinoket Lake on the east, which, according to Wells, has an area of eighteen square miles, while to

Pemadumcook, including Ambejijis, is assigned an extent of sixteen square miles. The whole constituted one lake with two outlets, a case rare in Maine. The formerly connected lakes are now separated by a wide lagoon and a bush-grown sand-flat of four rods wide, products of detritus brought down by the river. In times of flood, boats still pass freely from one to the other. Millinoket at present has for its outlet a stream bearing the same name as the lake, which, rising from the eastern end, flows south into Shad Pond, the lowest lake-like expansion of the Penobscot. The lagoon, through which in 1871 we were barely able to thrust our light boats, was now a broad surface of mud, impassable by boat or on foot, and an effectual barrier to the extension of our soundings and exploration into Millinoket. That this lake, as to its surroundings, is not unlike the neighboring ones, we are confident from our recollections of a pretty careful examination of it made in the previous visit. They agree with the statement of Dr. Jackson, that "the islands are composed of the detritus of granite rocks, and the shores are composed of the same materials."* Seen from the summit of Ktaadn, the outspread Millinoket presents in a marked degree those flowing outlines of gently rounded bays which distinguish lakes enclosed by detritus from the angular, irregular, and often narrow recesses that are said to characterize lake basins excavated in solid rock. Of the latter class I know not an instance in Maine.

The following tables register soundings made at intervals in what appeared to be the deepest parts of the lakes we navigated. Casts were made from the two boats, running some distance apart, and commonly in nearly parallel lines. The columns marked A contain the results of soundings taken by myself, with the assistance of Mr. Blake. The columns B give soundings made by Mr. C. B. Wilson from Dr. Crosby's boat. The figures show that the lakes represented, with the notable exception of Schoodic, have bottoms that are generally flat; and noting the nature of the materials that compose the shores, the lake beds would seem to be hollows, which had their origin in irregular accumulations of drift deposited on broad, flattish surfaces.†

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* Second Report on Geology of Public Lands, 1838, p. 11.

† G. W. Taylor, Esq., a resident of Cazenovia, Madison County, N. Y., writes as follows respecting Cazenovia Lake, which is one of the feeders of the Erie Canal, and situated in a valley surrounded by hills: —"Mr. Ledyard, one of the old inhabitants, made many soundings before I came here to reside. The bed of the lake [four miles long by three fourths of a mile wide] is as level as a valley; about one third of its area varies in depth only from 43 to 46 feet, — the latter being the greatest depth. The south end [the foot] of the lake is quite shallow."

I. *Upper Joe Merry Lake.*

		Ft.	In.
Off east shore, from middle of that shore to south end of lake	1	28	
	2	32	
	3	36	
	4	38	
	5	42	
	6	43	4
	7	44	8
	8	44	
	9	40	
	10	38	
	11	32	
	12	26	
South of South Island	13	38	
	14	36	
	15	34	
	16	40	
West of South Island	17	36	6
	18	40	
	19	42	
North of South Island	20	42	
	21	40	
	22	38	
East of South Island	23	36	
	24	38	
Up centre of lake from south end	25	40	
	26	42	
	27	44	
	28	42	
	29	40	

II. *Middle Joe Merry Lake.*

Running along central part from lagoon on south to vicinity of outlet at north.

A.

	Ft.	In.
1	10	
2	10	
3	15	
4	15	
5	14	8
6	14	7
7	15	3
8	15	
9	11	
10	15	
11	14	11
12	13	
13	16	4
14	18	
15	18	2
16	17	
17	16	
18	17	

B.

	Ft.	In.
1	14	4
2	14	6
3	16	3
4	13	9
5	7	
6	9	11
7	16	4
8	6	
9	13	8
10	12	
11	15	10
12	16	7
13	18	

III. *Lower Joe Merry Lake.*

From entrance on south, along middle 1½ miles to northwest, till stopped from sounding by wind.

A.			B.		
	Ft.	In.		Ft.	In.
1	20	4	1	15	4
2	22	2	2	16	5
3	22	4	3	20	4
4	10	6	4	22	4
5	25		5	20	
6	29	7	6	20	
7	30		7	21	
8	30	7	8	23	10
9	33	1	9	24	2
10	33				

IV. *Pemadumcook Lake.*

Running southeast toward foot, west of middle. Soundings began off small island near mouth of Lower Joe Merry outlet, and continued 2½ miles down, till stopped by wind.

A.			B.		
	Ft.	In.		Ft.	In.
1	13		1	13	
2	15	8	2	23	
3	23	5	3	36	6
4	37		4	30	
5	29	4	5	28	2
6	28	7	6	24	9
7	15	10	7	23	
8	24	4	8	17	
9	20	10			
10	17				
11	17	3			
12	14	7			

From foot, east of middle, in northwest course, about four miles, nearly to Gull Rock on east shore, opposite mouth of Lower Joe Merry outlet.

A.			B.		
	Ft.	In.		Ft.	In.
1	12	9			
2	13				
3	12	5			
4	11	7			
5	15	8			
6	17	5			
7	21		1	21	4
8	21	6	2	22	
9	19	6			
10	16	4			
11	23	2			
12	23	6			
13	23	9			

V. *Ambejijis Lake.*

Along middle, from foot, north to head, about two miles.

A.

	Ft.	In.
1	9	3
2	10	4
3	10	1
4	15	9
5	14	
6	16	9
7	25	4
8	26	9
9	30	
10	51	6
11	26	4
12	25	7

B.

	Ft.	In.
1	7	
2	18	
3	35	4
4	44	6
5	35	3
6	37	6
7	25	4

Cast 12 was quite distant from 11, and near entrance of Penobscot into lake.

VI. *Schoodic Lake.*

Numbers 1 to 25 give soundings from south end north, along course of west shore, but well out from it; 26 to 38 were taken off east shore, going from south to north; 39 to 50 are soundings made in March, 1881, through holes cut in ice along centre of lake, from south to north, at intervals of half a mile. Taken by Mr. Isaac Clapp, who speaks of his soundings as showing that "there is a mound near the centre of the lake 105 feet high," above the adjacent deepest parts.

		Ft.
1		37
2		65
3		100
4		100
5		87
6		86
7		63
8		25
9		28
10		16
11		12
12		17
13		56
14		72
15		70
16		79
17		90
18		90
19		100
20		51
21		37
22		39
23		28
24		28
25	At north end	14
26		120
27		120
28		97
29		100
30		104
31		106
32		100
33		70
34		63
35	Off Five Islands	100
36		95
37		95
38		28
39		110
40		140
41		140
42		142
43		73
44		40
45		145
46		100
47		90
48		120
49		122
50		90

VII. *North Twin Lake.*

Soundings taken by Mr. Wilson, along middle, from north to south, about two miles. Mine were lost.

	Ft.	In.
1	19	
2	18	3
3	16	
4	22	4
5	23	
6	22	4
7	19	6
8	19	

An Unreported Kame.

From a spot on the western shore of Middle Joe Merry Lake, known to the guide as Gordon's Landing, a name derived from former lumbering operations, a "horseback," or kame, runs two and a half miles north 28° west, forming for some distance the shore of the lake. On examination it proved to be an interesting specimen of its kind. It slopes at each end gradually to the general level, but through all the central portion maintains a tolerably uniform height. At a fairly representative point, it was found to have at its slightly rounded top a width of 15 feet, and by use of a clinometer and level the inclination of the east side was ascertained to be 30°, and the height 39 feet above the lake. The west side has an angle of 25° and rises 26 feet above an old pond of equal length with the kame, now changed to a swamp, only the width of the kame intervening between the swamp and the lake. Many granite bowlders of from one to two feet or more in diameter are strewn upon the ridge at and near its summit. The smooth and unbroken surface of the kame seems to indicate rather that they were deposited upon the ridge subsequently to its formation, than that, having made part of the original structure, they were by denudation left projecting from its surface.

The Granite Area.

Doubts respecting the actual existence of the granite area represented in the geological map were suggested during a rapid passage, in 1869, over the route now taken. The facts already stated, so far as they bear on the theory of such an area, do not go to sustain it. The observations now to be noted are more closely related to it.

From Gordon's Landing an excursion was made to Joe Merry Mountain, which is situated well within the limits of the supposed granite district, and is nearest and highest of the elevations that lie west from the chain of lakes. Showing upon its sides, as it does, bare cliffs through the forest that covers it, this mountain was chosen as a locality where we might hope to find some evidence of the nature of the rock underlying the vicinity, which, at the lower levels, had been hitherto concealed by thick drift deposits.

Dr. Jackson, while on his way to Ktaadn in 1837, saw this mountain from the shore of Ambejijis Lake, and describes it in these words: "From this spot I took a view of Joe Merry Mountain, which appears rising to a considerable elevation on the southwest. . . . . It is composed of granite, and is a commanding point of view for examining the surrounding country, so that it is frequented by explorers for timber." * But as Jackson was never nearer to it than when he ran down Pemadumcook Lake on the return from Ktaadn, it is evident that this statement rests merely on report.

A circuit of seven miles through the woods brought us to the foot of the mountain on its north side, where it rises at a sharp angle from the valley. For the last four miles of our way up to this point, the ground was thickly strewn with granite bowlders, which became larger and more numerous as we approached the mountain. So far neither rock in place, nor bowlders of other material than granite, had anywhere been seen. But, 200 feet up from the foot of the steep northern face, we began to find mingled with the granite bowlders others of considerably altered mica schist. At the height of 450 feet, and again at 600 feet, above the base, we came upon exposed ledges of rock, the same in kind as the newly found bowlders. So far the ascent had been abrupt. For the next hour it was more gradual, and several small levels and depressions were traversed. Later, a narrow and deep ravine was crossed, having on its farther side a cliff of schist, similar to that observed below, which rose at an angle of 35°, and so high as to require twenty minutes' sharp climbing to gain its top. Thence a gentle ascent was followed for ten minutes, when an elevation was attained of 1,635 feet above the lake, as determined by means of an aneroid, whose readings at various points were compared with simultaneous observations made by Mr. Blake with a Green's mountain barometer stationed in camp at Gordon's Landing. At this height numerous granite bowlders were still scattered over the mountain top. The mountain is a long ridge, running north and south. Its actual summit now lay

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* Second Report on Geology of Public Lands, p. 13.

perhaps half a mile before us, but scarcely more than 150 feet higher than the point already reached. As it was covered with forest, and promised neither outlook nor further revelation of the lithology of the mountain, and as our time was exhausted, we advanced no farther, but returned to the lake.

From the head of Ambejijis Lake, the route to Ktaadn for the next nine miles follows the Penobscot. For this distance, and in fact all the way from Shad Pond, below, to Chesuncook Lake, the river at short intervals widens into still lakes connected by rapid, rocky, and narrow reaches of running stream. As related to the falls and rapids, each of the numerous lake-like expansions is styled by rivermen a " dead-water." These remaining nine miles of water route include five falls, requiring as many portages of from twenty to ninety rods in length, each fall having below a dead-water bearing the same name as the fall itself. Thus Ambejijis Lake is the dead-water that lies below Ambejijis Falls.

While the prevailing and excessive drought greatly retarded travel upon the river, it afforded an unequalled opportunity to learn the nature of its bed, now bare to an extent unknown before for many years. One's conclusions with regard to the geology of the district south of Ktaadn must be shaped largely by the view he takes of the facts that relate to the nine miles of river bed here referred to. And since the previously recorded examinations of this part of the river were made in haste, and at times when high water in great measure hid the channel from observation, it seems best to state the very simple facts somewhat in detail.

Ambejijis and Passamagamet Falls, first in order, and a mile and a half apart, are caused by accumulations of large granite bowlders that choke up the narrow channel and give origin to the dead-waters next above them. To remove the bowlders would be to draw off the waters of those pond-like expansions. Not a trace of rock in place could be discovered in the river bed at either of these falls, nor upon the adjacent shores, which are elevated but a few feet above the level of the river.

The first ledge that appears upon the river or its expansions, from the foot of North Twin Lake northward, occurs twenty rods below the third, or Katepskonegan Falls, longest of the series, stretching seventy rods along the course of the river. The ledge, which is of granite, rises on the eastern shore directly from the water in a precipitous head of twenty feet in height. Northward to the falls, the east shore is a steep extension of the head, which inclines downward to the north, till at the falls themselves the ledge is to be seen only on the floor of the river bed. There is no exposure of granite upon the western side to match the high head upon the eastern; neither could rock in place be detected in the low banks of drift abreast the falls, nor along the carry. In the channel at the foot of the falls, the ledge was mostly hidden by accumulated granite bowlders, while at the upper part the water was seen to pitch over successive shelves of granite in place.

Though it was here that we first came upon fixed rock in the river bottom or banks, we had seen, half-way between this and the next fall below and some distance back from the west shore, two high forest-covered hills, which were the first considerable elevations met with since we left the lakes below. On the southern slope of each hill is a naked cliff. Circumstances rendered it impossible to land and push through the woods for a visit to the cliffs; and no second view of them occurred, since my return from the region took place by another route.

The passage through the dead-water of more than two miles to the fourth fall showed no trace of rock in place, either in the channel or along the shores. Nor did the neighboring low hills exhibit any faces of exposed rock.

Pockwockamus Falls, the fourth, occupy about twenty rods of the river's length, beginning abruptly from still water above, and ending as abruptly below in water of like character. The bed is an uneven floor of granite ledge, measurably free from bowlders in the middle third, but on each side covered with large blocks, mainly riven from the underlying fixed rock, which does not differ materially from that of the third fall.

At the fifth or Aboljacarmegus Falls, a mile above the fourth, is the next exposure of rock *in situ*. The river makes here a sudden bend, flowing from northeast to southwest, and is exceedingly narrow. The length of the fall is ten or twelve rods only, and the underlying granite differs strikingly from that of the third and fourth falls, and from that which makes up Ktaadn. In places it is highly porphyritic, and occasional patches of several square feet consist of massive feldspar or quartz, not constituting veins. At the third and fourth falls the granite, being highly jointed, has become divided into rhombohedral blocks of all sizes. Worn at the angles in various degrees by attrition, these make a large proportion of the bowlders that at both those falls conceal the rock in place over much of its area. At the fifth fall the fragments split from the solid mass in somewhat lenticular forms, never in rhombohedral blocks. About the foot, the only pot-holes anywhere seen occur in considerable number, but not of great size. Their presence here and absence from the falls below must be explained by difference in the texture of the rock at the localities, rather than by difference of other conditions. Along the portage past this fall are several small exposures of granite ledge, the only ones that were seen near the river, apart from its bed or banks.

The granite of the three ledge-formed falls, as well as that of Ktaadn, beyond any other that I have elsewhere seen, is free from veins and dikes. In fact the only instances observed of either in the whole region were a quartzose vein, an inch wide, that ran through a block twenty feet in length, evidently torn from the rock on which it rested at the fourth fall; and a small trap dike, four inches wide, that traversed a nearly buried erratic bowlder lying on the portage at the fifth fall.

Another circumstance common to the granite of the several localities is, that at the falls only is it visible. Above and below each fall the rock so suddenly and entirely disappears, that over the spaces between the falls granite in place could nowhere be discovered. It would seem, then, that at the third, fourth, and fifth falls a ridge of granite in each case cuts the river bottom transversely, damming the stream and obliging it in its course seaward to tumble in a fall over the lower slope of the ridge. The underlying fixed rock which intervenes between the granite ridges is so hidden by drift deposits that nothing can be asserted positively concerning its nature. One would naturally suppose it to be granite; but without attaching much importance to the marked difference between the rock of the upper fall and that of the two next below, there are other considerations, to be noticed presently, which suggest a doubt whether the three ridges that occasion the three ledge-formed falls have any lateral connection below the drift, and the question whether they may not be distinct ridges of intrusive rock, thrust up through strata from a common source beneath.

The theory that the district south of Ktaadn is part of a continuous granite region, is a hasty generalization from insufficient data, originally made by Dr. Jackson. Prof. Hitchcock, in his survey, which was discontinued at the close of its second year, made no personal examination of the Penobscot valley between Chesuncook Lake and Grand Falls. He therefore naturally adopted in the construction of his geological map Dr. Jackson's view of that district, supplemented by some testimony of one of his own assistants. The map was of course intended to be provisional only, and, had the survey been continued, would probably have been superseded by others. All the basis that exists for belief in a wide granite area south of Ktaadn is found in a few passages of Jackson's and Hitchcock's Reports. They can here be presented in small compass.

Jackson's notes of his trip to Ktaadn contain only the following brief statements respecting the rocks *in situ* which he saw on the way to and from the mountain. First, the one previously quoted in full, that Joe Merry Mountain "is composed of granite." * Second, that, "leaving our boats, we walked to Pock-wock-amus Falls, where the river rushes over a ledge of granite." † Third, "All the rocks at Quakish Lake ‡ are granite, and the water falls over huge bowlders of that rock." §

Dr. Jackson's assistant, Mr. J. T. Hodge, had preceded him by three months in the passage up the river. He speaks of but one of the two hills I have described as lying west of Katepskonegan Dead-water, saying: "On its western side is a high hill of granite, covered with immense loose blocks of the same rock, piled one upon the other almost perpendicularly." He adds: "Two miles above [a fall over "loose granite rocks"], we were obliged to carry by again on the western side. The opposite bank is formed of granite . . . . lying in the best position and form for working." Continuing, he remarks: "Not far above this we arrived at a fifth portage, which is called the Pauquakamus [in fact Aboljacarmegus]. . . . . At the head of this portage, the bank is a smooth ledge of granite." ||

Mr. J. C. Houghton, who for the year 1861 was Hitchcock's assistant, furnished for his report the following facts. In the account of a trip from Moosehead Lake down the Penobscot to Ktaadn and beyond, he notes that at the fourth and fifth portages "the river falls over ledges of fine granite." ¶ Respecting the fixed rocks upon the river and lakes below, he makes no further remark than that "near the outlet of North Twin Lake is the southeast limit of the granite, and the quartz rock [which he had last seen between Chesuncook and Ripogenus Lakes] again appears." **

Elsewhere Mr. Houghton mingles facts and conjectures. Having visited the "Katahdin Iron Works," †† which are situated in the township that corners upon Brownsville at the northwest, he proceeded twelve

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* Second Report on Geology of Public Lands, p. 11.

† Ibid., p. 14.

‡ Quakish Lake on Hitchcock's map is placed outside of the granite district, the last granite in place being now known to occur a little below North Twin Lake, *above* Quakish.

§ Ibid., p. 20.

|| Ibid., p. 53.

¶ Prel. Rep. Nat. Hist. and Geol. of Maine, p. 440.

** Ibid., p. 440.

†† A confusing misnomer, since they are situated full thirty miles in a straight line from the mountain whose name they bear.

miles farther northwest to a remarkable gorge, known as the "Gulf." This has been cut by Pleasant River for five miles through black slate that rises on either side in walls, sometimes to the height of from 100 to 300 feet, often vertical or overhanging.

He next "ascended Saddle Rock, a mountain which is about eight miles north 36° east from the Iron Works."* Its height he gives as "3,010 feet, being 2,416 feet above the ground in front of the furnace of the Iron Works." † He says again: "I was disappointed when I got to the summit to find it composed of the same slate formation that I had been on so long." After a few lines more he adds: "To the northwest are several mountains, the highest of which is called 'White Cap,' on account of its naked white summit, which, as a hunter informed me, is composed of granite. It is about eight or ten miles from Saddle Rock, and is probably near the southwest limit of the Katahdin granite region." ‡

This report of a "hunter," and Dr. Jackson's false statement, grounded on hearsay, that Joe Merry Mountain is made up of granite, constituted Mr. Houghton's only warrant for considering the granite district to extend beyond the Pemadumcook chain of lakes, and so far south as the northern line of the township next north of Brownsville, as is represented upon the geological map. Furthermore, the fact that, in the whole forty miles of the route between Ktaadn and the imaginary southern line of the district, granite has been found coming to the surface, over exceedingly narrow areas, in *five* localities, — viz. at the third, fourth, and fifth falls, near the outlet of North Twin Lake, and at the Upper Joe Merry Lake, — furnishes a very slender basis for belief in the existence of a continuous granite area south of Ktaadn.

Suppose we concede to be made up of granite the cliffs seen by Mr. Hodge and myself on the hill, or hills, west of Katepskonegan Dead-water, and apparently identified by him as granite through a distant view gained as he passed up the river in his boat; and White Cap, *reported* to consist of granite by one whom we do not know to have learned its character from personal examination. With these additions we have data still entirely insufficient to justify the conclusion that has been drawn from them.

The sudden appearance, and as sudden disappearance, of granite in districts covered by stratified rocks, are characteristic of Central Maine. The granite not uncommonly occurs as isolated hills separated by a greater or less extent — sometimes by a score of miles — of unbroken strata. The same reasoning that would make the district south of Ktaadn a continuous granite area, would apply as well to others known to be underlaid by strata through which granite shows itself in detached hills or ridges.

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* Prel. Rep. Nat. Hist. and Geol. of Maine, p. 430.

† Ibid., p. 430.

‡ Ibid., p. 431.

The case of Augusta, situated near, but not at, the southern border of the region of slates and schists, is instructive in this connection. The conclusion which even a geologist looking over that vicinity in haste might feel to be the natural inference from obvious and abundant data, would nevertheless be a wholly false one. An outline of the case only can here be given. Augusta city is built on both sides of Kennebec River, upon well-developed terraces which form the sides of a valley that has there been excavated to the depth of 300 feet below the level of the adjacent country. The width of the valley east and west, from summit to summit, is a little over one mile in a straight line, and midway runs the river in a course somewhat west of south. The terraces and summits on either side are composed of drift deposits, so thick that the deepest wells nowhere reach solid rock; and four sharp ravines, that on the western side cut the terraces down to the level of the river at their mouths, have bottoms and sides of drift, as has the river bed, except at two points. The highest part of the western summit is a "granite" ledge which rises in a knob some thirty feet above the rest of the summit and the general level of the country. Its top has an area of not more than one or two acres, and falls off rapidly on the north, east, and southeast beneath the enveloping drift. A mile south of this point, and half a mile southwest from the State House, is a broad hill, about 400 feet in height above the river. On its southwest side, which lies in Hallowell, are the quarries that furnish the well-known "Hallowell granite." The hill throughout is a solid mass of the same material. In riding out of town two miles to the west, northwest, or northeast, one comes upon several "granite" quarries in each direction. In view of the foregoing facts, a visitor would feel himself justified, if no further examination were made, to pronounce "granite" to be the underlying rock of the vicinity. But should he notice just across the railway track from the station, at the foot of the second terrace, forty feet above the river and 200 feet from it, an exposure of rock now mostly hidden by a granite bank-wall, he would find it to consist of hardened, upturned schist; and in the drought of summer he would see in the river bed, for a few rods above and below the railway bridge, ledges of the same schist.

Across the deep, narrow valley of a tributary to the Kennebec, above half a mile in an air-line northeast from the granite knob before mentioned, and at the northern limit of the city proper, rises more than 300 feet above the river what was formerly known as the Andros Hill, the upper part of the so-called Cushnoc Heights. On the southeastern slope of its upper hundred feet, on nearly the same level with the road, but on the opposite side of that part of the hill, and so hidden from the view of the passer-by, is an abandoned quarry of mica schist. Here, too, the rock plunges off on the south, east, and west beneath an unknown depth of drift.*

Finally, should the observer examine, for the four miles that intervene between Andros Hill and the northern line of the township of Augusta, the very few exposures of rock in place that occur along the river road on the west side of the Kennebec, and upon the farms crossed by the road, he would find in every case schist, and that only. Upon the corresponding road east of the river, only schist is found for the whole six miles of its length across the township. It is evident, then, that the underlying rock of Augusta is the upturned schist, which becomes at Waterville, eighteen miles north of Augusta, the almost vertically placed Taconic or Lower Silurian slate that stretches to Moosehead Lake on the north, and easterly to and beyond the city of St. John, N. B.

In the great denudation which this extensive region has undergone, the more resisting granites † of Kennebec County have been left projecting as hills above the softer schists, which, worn down to lower levels, have been covered with deposits of drift, frequently of great thickness. For miles these lower grounds and the hills also may be traversed without meeting any indication of the nature of the underlying rock. Thus, upon the road along the western side of the Kennebec, between Andros

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* Half a mile above the bridge, at the foot of Cushnoc Heights, is the Kennebec Dam. In 1839 a freshet swept away seven acres of land at the west end of the dam, and cut a new channel for the river 500 feet in width, the floor of which, when the waters abated, was found to be a transverse ridge of well-marked mica schist. In extending the dam across the new channel, the rock thus laid bare was soon after hidden again from view.

† The so-called granite of Hallowell and Augusta was termed by Jackson "granite gneiss" (First Rep. Geol. of Maine, p. 83), and is declared by Dr. T. Sterry Hunt to be "true gneiss" (Am. Jour. Sci., [3.] I. p. 85). But is the sudden transition, in so many places within a small area, from crystalline rock to distinct schists, compatible with the idea that the former is a metamorphosed portion of the latter? Are not the relations of the two more consistent with the hypothesis that the "gneiss" is in reality eruptive granite, which in its passage through the strata has changed the original slates into hardened schists?

Hill in Augusta and Waterville, I remember but five small spots where rock *in situ* rises to the surface. Upon the adjoining farms a few others may be observed. All are little patches of outcropping strata. Going northward from Augusta, wherever the strata are harder than usual they rise into hills. At Waterville, while fissile slates occupy the low grounds, they lose the slaty structure and pass into hard schists in several high hills, one of which presents a bold, precipitous face. The numerical proportion of such hills increases farther north, till, south and east of Moosehead Lake, so far as examination has been made, hills and mountains of schist far outnumber those composed of granite. Isolated granite hills occasionally rise in districts of slates and schists, but nowhere is anything to be found that can be termed a granite district. Judging from the foregoing facts and instances, we must think, until stronger proof to the contrary is produced than at present appears, that the country south of Ktaadn, to and beyond the Joe Merry Lakes, is part of the great region of stratified rocks which surrounds it on all sides. On such an hypothesis, the presence of Joe Merry Mountain where it is — a mass of schist — is comprehensible; but how shall it be accounted for if supposed to rise out of a granite district?

On arriving at the mouth of the stream where the trail from the river to the summit of Ktaadn begins, it had been my purpose, before making the ascent of the mountain, to run up the Penobscot twelve miles farther, to Ripogenus Portage, upon which occurs the border line between the granite and the stratified rocks in that direction. But lack of water in the river, and its obstruction by great gatherings of logs, formidable enough below and known to be worse above, made further boating impracticable. The Ripogenus trip was therefore unwillingly relinquished.

Of the northwestern portion of the so-called granite district, I can speak, then, only from notes and recollections of a canoe excursion made in 1871 from Moosehead Lake downward. They enable me to say, however, that the river's course, from the Ripogenus Gorge to Sourdnahunk Falls, lies chiefly among hills. Those on the north skirt closely the left bank of the river, and are foot-hills of the Sourdnahunk Mountains, which are a little beyond. The hills are frequently precipitous, presenting a frontage of granite cliffs. Except at the Ambajemackomus Falls, where the river plunges eight or ten feet over a shelf of granite, I have no distinct remembrance of ledges in the channel, which is thickly strewn with granite bowlders. But the character of the heights adjacent upon the left leaves no room for doubt that, between the limits specified, the Penobscot flows over underlying granite, superficial or drift-covered.

Mount Ktaadn, as we shall see, is composed wholly of granite, and its relation to the Sourdnahunk Mountains, which extend from Ktaadn westerly ten miles, is such that it and they must be regarded as parts of one continuous range. It cannot be doubted, therefore, that a Ktaadn "granite area" exists, having for its length that of this range, and including on its southern side the channel of the Penobscot, at least so far down as Sourdnahunk Falls, which are three miles above the mouth of Aboljacarmegus Stream. These statements are confirmed by the few observations upon this part of the river which the Geological Reports record.

The floor of the Great Basin of Ktaadn has an elevation of 2,900 feet above the sea. As one goes outward from it by the present route to the East Branch of the Penobscot, better styled the Mattagamon River, he skirts along the northern foot of the abrupt portion of the eastern mountain. On leaving that, he quits the last trace of rock *in situ*, which nowhere reappears in the descent of more than 2,400 feet made along the twenty-three miles of way to the crossing of the Mattagamon at the Hunt Place. There is abundant testimony that ledges do not come to the surface on the old Keep Path, which diverges from the present route at Ktaadn Lake and runs seven miles to the foot of the East Slide. It is certain, then, that on the east side of Ktaadn granite has not been discovered upon the gradual lower slopes of the mountain, which make up nearly half of its whole height. It is certain, too, that just beyond the western or Sourdnahunk end of the range, the granite disappears beneath the surface. To the south of the Sourdnahunk Mountains, as we have seen, granite without doubt makes up the river channel; but the aspect of the low country to the south warrants the supposition that granite as a superficial rock extends in that direction not far beyond the Penobscot. It seems, therefore, in the highest degree probable, that the Ktaadn "granite area" includes little but the mountains themselves, and that, nowhere extending far out from the foot of the range, it does not, in some parts, embrace even the lowest slopes.

Mount Ktaadn.

The low country south of Ktaadn has an average elevation of not more than 550 feet above the sea. From it rises the mountain by moderate gradations to less than half its altitude, or about 2,200 feet on the south side, but the upper portion, rearing itself 3,000 feet higher, is bounded by declivities of great abruptness.

A brief description, illustrated by the accompanying heliotype of a model which represents the upper three thousand feet of the mountain, will render intelligible subsequent references to the general features of Ktaadn.

The crest that bears the highest peaks is bent like a deep crescent, opening north, and enclosing the Great Basin. At the centre of the crescent are the two chief peaks, which differ in altitude less than twenty feet, and are not more than a third of a mile apart. Directly beneath the East Peak, shoots off to the southeast the longest of all the spurs, which, narrow above, widens greatly towards its foot. Beyond the peaks, the eastern horn of the crescent includes a thin, serrated crest, and forms at its tip, first, the little tower-like peak known as the Chimney, and then, across a narrow, square-cut notch, the peak of Pamola,* named from the Indians' demon of the mountain. It is known to many only as First Peak, so styled because it was the first summit reached by tourists who followed the original eastern route to the mountain. Pamola has a regularly convex, wide northern face, that runs down with a precipitous foot to the level of the basin floor, nearly 2,300 feet below the highest peak. Eastward from Pamola projects a narrow, sharp-ridged spur, the "Horseback," — an unfortunate name as here applied, since in other cases it invariably means, in Maine, a kame, with which this buttress of solid rock has nothing in common. Towards its extremity, the "Horseback" forks, and sends off to the northeast a lower, flat-backed spur, while on its southern flank is the East Slide, — the smaller of the two great slides that are among the peculiar features of Ktaadn.

Against the western horn of the crescent abuts the Table Land, an almost absolutely plane surface, inclined to the northwest at an angle of from five to seven degrees, and having a length of a mile and a half, and an area of more than five hundred acres. The centre of this plateau is a few hundred feet lower than the highest peak, which has an elevation of 5,215 feet, as determined by Prof. Fernald. Half a mile below the middle point of the sharp brow that bounds the Table Land on the south is the head of the Southwest Slide. This slide is the track of an enormous avalanche, which, in 1816,[*] swept over a course of not less than four miles in length. A mile or more of the lower part is now wholly grown up to forest, but the upper part, for a mile and three fourths, is still covered with loose fragments of rock and gravel, upon which vegetation has not encroached, except along the sides. The East Slide is less than a mile long.

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* The name as given by Jackson and those who have followed him is *Pomo'a*. I have chosen the form *Pamola* on the authority of Rev. Eugene Vetromile ("The Abnakis and their History," pp. 63–67), for many years Catholic missionary among the Indians of Maine and New Brunswick. Dr. De Laski, in a paper to be referred to farther on, applies the name incorrectly to the "apex of Katahdin."

The Table Land narrows on the west, and sends off a sharp-ridged spur that curves to the southwest. From West Peak there is a descent northward and westward, into which the Table Land merges, down to the level of 4,250 feet, — the lowest part of the central mountain, termed the Saddle. Northward from this rises rather gradually a rounded summit 450 feet higher than the Saddle, or 4,700 feet above the sea, and 515 feet lower than West Peak. Three fourths of a mile farther northeast is a second summit, similar to the first, but slightly lower, the two being separated by a moderate depression of the ridge. A half-mile farther, in the same direction, follows a third rounded summit, perhaps seventy-five feet lower than the first. From the first and second northern summits run eastward two sharp and narrow spurs, which include the North Basin, so named to distinguish it from the Great or South Basin. The northern face of this smaller basin is made up of cliffs for the most part nearly vertical. From the second summit runs west another long and flat-topped spur.[*]

Beyond the Saddle, the mountain stretches some seven miles to the northeast, and terminates in a knot of lower spurs, having in the main flattish tops and precipitous sides.

The Great Basin, in its whole extent, forms an amphitheatre, which, seen from above, strongly resembles an old volcanic crater. In the absence of trigonometrical measurements, its dimensions cannot be accurately stated ; but they may be approximately given as from summit to summit east and west two and a half miles, by a mile and a half from north to south. Its most precipitous part, the southern lobe, measures from its head to the Basin Pond about three fourths of a mile, and its width is nearly the same. The smaller North Basin approaches in shape the capital letter U, and is about a mile and a half long and half as wide, fronting a little south of east. The larger basin has a narrow gateway opening to the northeast.

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[*] Williamson's History of Maine, Vol. I. p. 90.

[†] In photographing the model, light fell upon the western spurs exactly in the direction of their length. Flooded thus with light, these parts have not enough of shade to render them distinct.

The wall of the Great Basin rises highest above its floor on the south, becoming gradually lower on the east and west sides. The height of West Peak above the Basin Pond, as determined by the mean of six pairs of simultaneous observations taken with a Green's mountain barometer at the level of the pond, and with an aneroid upon the peak, was found to be 2,287 feet, which is the depth of the basin, measured downward from the top of the same peak. Its walls on the south and east are so steep that they have never been climbed, except at one or two points, as an act of foolhardy daring. The height of Pamola above the little pond, as estimated from a single pair of simultaneous observations, is 1,891 feet, or 396 feet less than that of the highest peak.

It is within the walls of the Great Basin, and upon their summits, that the geology of Ktaadn can best be studied. The whole mountain, from the lowest point where rock in place has been discovered, is composed of granite. Of this, five specimens, numbered 3, 5, 23, 25, and 57, have been examined by the lithologist of the Museum, Dr. Wadsworth, whose notes upon them are here given. In a general description of the mountain, it may be said that it is made up of two varieties of granite, the gray and the red. To the first variety specimen 3 belongs; to the last, belong 23, 25, and 57; 5 being in a manner intermediate between 3, on the one hand, and 23, 25, and 57, on the other.

Dr. Wadsworth's Notes.

No. 3. — A gray granite, composed of feldspar, quartz, and biotite. The feldspar is of two kinds: a grayish-white one, with a pinkish tinge, is the most abundant, while subordinate to it occurs a milk-white striated feldspar. The powder of the rock is magnetic. Under the microscope the thin section is seen to be composed of orthoclase and plagioclase, quartz, biotite, and magnetite. The orthoclase is much decomposed and cloudy, showing only feeble polarization. The plagioclase, in general, is much less altered, and shows its triclinic character well in polarized light. Some of the crystals, however, show the characteristic banding only in places, principally at the ends and sides of the crystals, while in the more altered portions the twinned structure is rarely seen. This alteration renders it very uncertain that the supposed orthoclase is really all so; and we feel that this has been a fruitful source of error in the microscopic examination of rocks. The quartz contains numerous fluid inclusions, moving bubbles being seen in them; it also contains trichites and minute crystals. These crystals are probably apatite and zircon. Some apatite crystals were seen in the feldspar.

No. 5. — A pinkish gray granite of the same composition as No. 3, the difference in color being due to the deeper color of the feldspar. It shows in the thin section similar characters to No. 3, except that the feldspars are more decomposed, and therefore less plagioclase could be seen, while the quartz contains more abundant trichites.

No. 23. — A brownish red granite of similar composition with the preceding. Feldspars colored pink and greenish white. Calcite and a greenish talcose mineral occur as alteration products. In the thin section the feldspar is seen to be greatly altered, and but very little of it shows any trace of triclinic characters. The biotite is partly decomposed, and has a greenish color. The general character of the rock is slightly more basic than the two preceding, but we do not consider that there is enough difference to lead us to regard them as distinct. We should rather regard them as parts of the same formation.

No. 25. — In this specimen the greenish feldspar predominates over the pink. The rock shows abundant signs of weathering, containing numerous cavities formed by the decomposition of its ferruginous minerals, and now partially filled with hydrous oxide of iron. Under the microscope this is seen to be the most decomposed of any of the specimens, the biotite being almost wholly changed, and almost no plagioclase being recognizable. Many parts of the rock are filled with viridite. The quartz, besides its numerous fluid inclusions, contains dodecahedral quartz crystals of the same character as those so commonly seen in the quartz of rhyolite. This rock is similar to No. 23. We should regard these rocks as eruptive, but we are well aware that others would claim that the microscopic characters are those which belong to metamorphosed sedimentary rocks.

No. 57. — This rock is seen in the hand specimen to be composed of flesh-red orthoclase, pale greenish white feldspar, somewhat decomposed, together with altered biotite and quartz. The biotite has been changed to a chloritic material. The minerals give to the rock a greenish red color. It is more coarsely crystalline than the other specimens from Mt. Ktaadn, and in its general facies is somewhat unlike specimens 3, 5, and 25.

The lower two thirds of the basin walls are composed of the gray granite, which is similar in composition and appearance to that of the lower slopes of the mountain on the south side, and to that of Katepskonegan Falls, except that the rock of the localities last indicated contains only the white feldspar. The upper third of the walls consists chiefly of the red variety (5), the modifications represented by Nos. 23, 25, and 57 being found only upon the very highest parts of the mountain, — the East and West peaks, the serrated crest, and the ridges that connect those portions. The rock represented by the last three numbers is throughout so badly decomposed that only once was a specimen (57) obtained tolerably sound and firm under the hammer. The rock represented by No. 5 is oftenest, but not always, found in a crumbling condition; while the gray variety (3) is generally comparatively solid, but occurs in a few places in the last stages of disintegration.

From the shores of the Basin Pond, where an unobstructed view is to be had of the whole height of the walls, the granite, up to two thirds the height of the eastern side, or about the upper limit of the gray variety, is seen to be arranged in concentric sheets, that dip west at an angle varying from 45° to 60°. On the southern wall the same concentric arrangement prevails, the layers dipping north, often at angles higher than 60°. Above the part that lies in concentric sheets is the red granite, which divides, on weathering, into blocks more or less regular in form. Near the head of a torrent that comes down from the Saddle, in two instances the red variety (5) lies in blocks, with forms so definite as strongly to resemble courses of cyclopean, but crumbling masonry. At the foot of these "castles" the rock is so friable as to fall into gravel under the tread.

What has been said of the occurrence of the red and gray granites, at different elevations, does not mean that they are separated from each other by any well-defined horizontal plane. They are undoubtedly parts of one and the same formation, and, as in the quarries of Quincy and Cape Ann a variety of rock having one color passes into a variety of another color so gradually that the separation cannot be said to take place along any line, or plane, so at Ktaadn the red and gray granites merge into each other in the same way, and at various levels. Yet it is substantially true that the lower two thirds of the basin walls, and probably the whole of the mountain mass below the level of the basin floor, consist of the gray, and the upper 700 feet of the red granite.

As has been remarked already, the granite of Ktaadn is singularly free from dikes and veins. During the explorations made both in 1879 and 1880, not a dike or vein was discovered, either in the fixed or loose rocks of the mountain. We have seen that the same was true, with but two exceptions, of the ledges and bowlders that were observed upon the Penobscot. The absence of these characteristics of older rocks will be held to indicate that the granite of Ktaadn and its vicinity is of comparatively recent origin.

The only considerable departure from the normal granitic type is the occurrence of very numerous inclusions which resemble imbedded fragments of foreign rock. Like patches are common in most granites, but I have never known elsewhere so many as the Ktaadn granite presents. Upon the talus beneath the east wall of the basin a small block of red granite was observed which contained five visible inclusions, varying from two and a half to seven inches in diameter. In respect to numbers, this was an exceptional case, but single inclusions met the eye at every turn. Of specimens collected in the basin, some have their outlines sharply defined, but others merge gradually into the enclosing granite. As usual, they are finer in grain, and of darker color, than the surrounding rock, being commonly of a deep gray, but sometimes lighter from the presence of imbedded crystals of white feldspar. Upon the Southwest and East Slides a few inclusions were found of another character. Of these, one was brought away from each locality, — the best of its kind. They seem to be fragments of almost black mica schist, are angular on all sides, are separated from the granite by lines perfectly distinct, and were selected as pieces of foreign rock which had been caught up by the granite and included within its mass.

Inclusions in granite have long attracted attention, but have not been the subject of much investigation. A clear and extended discussion of their nature, with figures of specimens and a record of analyses, may be found in a paper, by J. Arthur Phillips, entitled "On Concretionary Patches and Fragments of other Rocks contained in Granite." * In his "General Conclusions," the author makes the following statement: "The inclusions contained in granite are of two distinct kinds. Those of the first class [which are spoken of throughout the article as concretionary, though not exhibiting a concentric structure] are the result of an abnormal arrangement of the minerals constituting the granite itself, while those belonging to the second represent fragments of other rocks enclosed within its mass." (p. 19.) Most of the patches observed in the basin must be assigned to the first class, while the specimens brought from the slides seem clearly to belong to the second.

The forms which the several parts of the mountain now present, and the condition of their surfaces, are largely due to the original structure and mode of weathering that characterize the rocks. As the highly inclined concentric sheets in the basin walls break away, and fall upon the talus below, other faces of equal inclination are exposed; while the red granite of the higher parts, deprived of support, in turn gives way, and thus the steepness of the walls is maintained. Similar steep faces, due to the concentric structure of the granite, abound upon other parts of the mountain, as on the flanks of several spurs, and about the base at various points.

The crest (a feature unique among Eastern mountains) that occupies most of the space between East Peak and the Chimney owes its form and

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* Quar. Jour. Geol. Soc. of London, Vol. XXXVI. pp. 1-22, February, 1880.

preservation to the circumstance that the modified red granite which makes it up divides in weathering into plates, which, when undisturbed, stand vertically on edge. They vary in thickness from an inch, or less, to upwards of a foot. Where their trend is in the same direction as the ridge, there, as they have become loosened, and have fallen over the cliffs on either side, the plates still left firm in place constitute a narrow crest. It is surmounted by a serrated edge, and, as one follows it for the fourth of a mile, alternately ascending steep projecting points, and descending into jagged notches between, he must again and again walk along a mere blade of rock from one to two feet wide, having upon one side the yawning gulf of the basin, and on the other cliffs too steep for climbing.

From the crest southwest to East Peak, and between that and West Peak, the rock plates stand crosswise of the ridge at various angles, and there, as they have been loosened by frost, falling more or less out of perpendicular, they still remain. Thus the blade-like form is lost, and the ridge is somewhat wider, though still narrow. Bristling with oblique, projecting plates covered with black lichens, these parts present a savage and chaotic desolation that is probably without a parallel in Eastern North America.

The very diverse conditions of surface upon the other summits — hardly their forms — may be traced sometimes to variations in the jointing of the constituent rock, but oftener to simple difference in firmness. Thus, parts made up of the more friable red granite (other than those modifications of it, represented by specimens 23, 25, and 57, that divide into thin plates, and are confined to the highest summits only) are covered with small-sized fragments, rounded by decay. These at times assume, over wide spaces, the size, and almost the arrangement, of cobble paving-stones, and in a few places the aspect of gravelled areas. Such are seen chiefly on the northern summits.

Again, the middle of the northward slope, between the Table Land and the Saddle, is piled with blocks of the firmer red granite, riven from the mass beneath, of size so great as to render travel over them extremely difficult. The Table Land is in parts smoothed by a covering of wholly disintegrated material, but in general is strewn with tabular blocks that increase upwards toward West Peak in size and number. The half-mile between the head of the great Southwest Slide and the brow above is literally a heap of huge blocks, constituting a slope that varies from 36° below to 47° above.

The slopes south from the two chief peaks are covered with loose, angular, often tabular fragments, as far down as to the tree line, which is everywhere upon the mountain very low, leaving an unusual amount of naked rock above. These slopes present much the same appearance as does the top of Mt. Washington southward from the Summit House toward the Lake of the Clouds, except that on Ktaadn the blocks are larger, and the slopes much more abrupt.

All the summits so far described are bare of vegetable growth larger than lichens, or shrubs like the mountain cranberry, almost as diminutive as mosses, and are therefore open to close inspection. The whole rock surface has been so shattered that only on faces of cliffs too steep to allow the accumulation of detritus is rock in place to be found. To the east spur of Pamola, the "Horseback," the last statement will not apply. This narrow ridge may be said, in a great measure, to have *shed* its ruins as they have been formed. Consequently, the spur, over all its upper part, exhibits along the ridge abundant granite in place. Here, of course, the present surface is of recent origin.

Except a few paragraphs in the brief accounts of hurried visits made to Ktaadn by Dr. Jackson and Prof. Hitchcock, contained in the Maine Geological Reports, a brief article by the late Dr. John De Laski,* of Vinalhaven, and a reference of three lines in the second and third editions of Dana's Manual of Geology, based upon an erroneous statement of De Laski's, I recall nothing in print that specially relates to glaciation in connection with Ktaadn. Prof. Fernald's observations for the latitude of the highest peak make it to be 45° 53′ 40″. The parallel of 46°, therefore, crosses the northern base of the mountain. Farther north than Mt. Washington by over one degree and a half, and, according to the computation of Mr. W. H. Pickering, 161 miles distant from it in a straight line, and of New England mountains inferior in altitude only to the highest summits of the Washington group, Ktáadn becomes of so much interest that, but for the inaccessible nature of the region, the mountain and its vicinity would long since have been thoroughly explored for testimony upon the question of a great northern ice-sheet, and the existence of former local glaciers.

As might be expected, upon summits changed from the original condition to the extent that has been indicated, days of search failed to discover any signs of glacial striæ, or polish. Examination for them was made also, without result, on the lower slopes: first, where the trail from the Aboljacarmegus Stream, about a mile from its beginning, crosses a succession of bare granite areas, and at the next exposure of granite in the course of the trail, which is just at the foot of the present terminus of the Southwest Slide. At both localities the rock is of the coarse gray variety that is exposed at the third and fourth falls, and is destitute of glacial markings. The surface is honeycombed by decay, which, at the lower station, has gone so far that it was there impossible to break out, with a heavy hammer, specimens which at all approached a sound condition.

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* Am. Jour. Sci., [3.] III. pp. 27–31, 1872.

The only rock in place to be seen upon the Southwest Slide occurs two thirds the way up from its foot, at an elevation of about 3,500 feet. It is a fine-grained, dark gray granite, approaching in appearance some of the inclusions that are found in the basin, and well adapted to resist decomposition. It lies, as at the stations below, in concentric sheets,* which have here an inclination of about 30°, and is smooth, hard, and free from all indications of decay; but not a scratch or other sign of glaciation appears upon it. It is a small area, only seventy-five feet along the slope, and perhaps a third as wide, and disappears above, below, and at the sides, under the débris of the slide, beyond the slanting face of which the ledge scarcely projects. If it was first uncovered, in recent times, by the descent of the avalanche of 1816, as from the surroundings seems not improbable, the absence here of grooves and striæ is significant as respects the glaciation of the higher parts of the mountain.

If evidence of glaciation upon the summits of Ktaadn exists, it must be other than that to be derived from smoothed and striated surfaces. It will be maintained by many that such evidence is supplied by the flat tops of the Table Land, and of several of the spurs, and by the well-rounded northern summits and faces. To this it may be objected that table-topped mountains are not wanting in regions where neither drift nor other indications of glaciation have been recognized. The statement, however, is open to the rejoinder that, in such cases, the shape may be rationally accounted for by obvious peculiarities of structure, as is the typical instance of Table Mountain, near the Cape of Good Hope, which is a mass of granite capped by horizontal beds of sandstone. The prevalence of steep faces upon the sides of Ktaadn, as already remarked, is to be ascribed ultimately to the high inclination of the concentric sheets of granite; but there is absolutely nothing in the rock structure that will help to account for the existence of a great plane surface of above five hundred acres, like that of the Table Land. The supposition that it is the work of moving ice is a natural and rational one, provided the weight of proof in support of such an hypothesis is greater than that of proof antagonistic with it. But to cite testimony for, or against, any particular theory, does not come within the scope of a brief paper like this, whose chief purpose is the presentation of facts.

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* My observation of Maine granites in general, and especially at Mt. Ktaadn, forces me to the conclusion that the concentric lamination of granite is due to causes connected with the original structure of the rock, and not, as has been maintained by Professors Shaler and Hunt, to superficial variations of temperature during the changes of the seasons. It would seem, then, to be putting terms in their logical order to speak of the conformity of present surfaces to the inclination of the granite sheets, rather than of the lamination as conformable with superficial features.

Material interesting from its relation to the transportation of drift, whatever may have been the agent that moved it from the north, is not wanting upon Ktaadn. The two slides furnish the chief amount of such material. The present Southwest Slide proper — the loose slide — begins a little above the point where the old avalanche started, a full half-mile below the brow of the Table Land, and terminates at the foot of the most abrupt portion of the mountain. The length between the points indicated, as estimated after repeated ascents and descents, is one mile and three fourths. The width at the bottom is about 100 feet, narrowing very slowly upwards. The difference of elevation between the top and bottom is 1,774 feet, — the mean of two observations. In its course the slide exhibits several terraces, at places doubtless where it conforms to the varying slope of the solid surface of rock over which it passes. The inclination, therefore, is variable. As tested with a clinometer at several points, it appears to be as follows. From the foot to the "Green Island," * a small bush-grown patch upon the surface of the slide, and 985 feet (mean of two observations) higher than its foot, the inclination of the slopes between the terraces varies upwards from 24° to 28°; thence to the top it is 31°. The average inclination of the rock-piled surface, from the head of the slide to the brow of the Table Land, is 35°, but the last seven minutes' climb is upon a slope of 47°. Along the lower two thirds of the slide, drift is distributed in considerable quantity, but on the upper third it is rarely seen, and disappears entirely before the top is reached.

The East Slide is less than a mile long, and is one continuous slope, uninterrupted by terraces like those of the Southwest Slide. The inclination of the lower half was found to be 25°; of the next fourth, 28°; of the upper fourth, 30°. Its foot lies about 200 feet lower than the level of the Basin Pond, and its head is 1,000 feet above the same level,

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* A landmark conspicuous for miles down the Penobscot, and recognizable in photographs.

making the elevation of the head above the foot about 1,200 feet. It had its origin in an avalanche which is said to have descended between 1820 and 1830. The two slides will in time disappear, as others before them doubtless have, by the slow encroachment of shrubby growth from the bottom and sides, now seen to be in progress. On the East Slide much less drift is found than on the other. Outside of the slides, I have never found drift upon the flanks of the mountain; but it reappears higher up, in very small amount on the Table Land, but principally upon the northern summits, sparsely strewn among the broken granite that covers them. Neither on slides nor summits is the drift ever found in large bowlders, but always as fragments of moderate size. On the Southwest Slide a *few* masses were seen as heavy as a hundred pounds each, but in general — always upon the East Slide — the pieces ran from a few ounces up to twenty pounds in weight. They were chiefly fragments of slates and sandstones, identical with the strata of the country north and west, mingled with pieces of metamorphic and trappean rocks, such as occur in place for a few miles beyond the Ripogenus Carry.

The fragments of stratified rocks on the Southwest Slide very generally include fossil shells, mainly Brachiopods, and always impressions or interior casts. Owing to the small size of the enclosing masses, — due to the fissile structure of the rocks, — the fossils ordinarily are much decayed, but occasional specimens are obtained in fine condition. Among the scanty drift upon the upper third of the Southwest Slide, I have never seen a fossil-bearing stone. And upon those parts of the summits where drift was found, only once was a fossil met with, — a solitary Brachiopod impression on a ten-pound piece of sandstone, picked up on the slope northward from West Peak to the Saddle, about 600 feet below the top of the peak, or at an elevation of about 4,615 feet above the sea. This is by far the highest point at which fossiliferous rocks have yet been found upon Ktaadn.*

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* Dr. De Laski's statement of the height (4,385 feet) at which he found fossils, "well up toward the 'Horseback' ridge" (Am. Jour. Sci., [3.] III. p. 27), and which is quoted by Prof. Dana in his Manual of Geology (editions 2d and 3d), is founded upon a wrong estimate of the altitude of the mountain. He adopted the one current for some years before Prof. Fernald's remeasurement of the elevation, which he made to be 5,215 feet. Now the elevation of the "Horseback" ridge, at a point directly up from the head of the East Slide, — Dr. De Laski's route, — we make 1,181 feet above Basin Pond, while that of the summit of Ktaadn is 2,287 feet above the same level. The difference 2,287 — 1,181 = 1,106 feet, the difference of elevation between the "Horseback" ridge, at the point named, and

For a purpose presently to appear, it is pertinent here to introduce an observation made by Prof. Hitchcock in the valley of Avalanche Brook, a stream that, starting from the gorge between the Chimney and Pamola, abruptly terminates the East Slide by sweeping away the detritus at its foot, which the brook passes nearly at right angles. This "valley," where we saw it, is only a rocky channel, heaped with bowlders of all sizes. In the dry season there runs, half hidden among the rocks, a rivulet, which, in times of flood, becomes a furious torrent, and fills the banks. Says Hitchcock: "We ascended the valley of Avalanche Brook on the south side of the mountain, and . . . . found an immense number of bowlders of Oriskany sandstone, many of them highly fossiliferous. . . . . We found none of these bowlders higher than the foot of the slide, although others have found them a few hundred feet higher." *

Among the other drift met with upon the slides, we found smoothed and striated stones, scratched uniformly in the direction of their length, and rounded at the angles. They are the first of their kind that have been reported from Ktaadn. The best were as fine examples of what are considered typical glaciated fragments as any that are figured as such in geological works. The largest, weighing from ten to fifteen pounds, were more deeply scored than the smaller; but being too heavy to be borne many miles in our packs, they were unwillingly left behind, and others of less weight were selected as specimens. Of two that were brought away, one is a piece of hard trap rock (determined by Dr. Wadsworth to be diabase) five inches long by two and a half at its widest part, and weighing twenty ounces. The other is a thin piece of fine-grained argillaceous sandstone, seven inches by three and a fourth, split from some larger stone that was not discovered. Of such striated fragments not more than a dozen in all were found upon both slides. They were rare exceptions among drift that showed no striæ. According to the testimony of books, and of several persons familiar with glacial phenomena from their own observation, the specimens agree precisely in character with stones worn at their angles, and grooved on their faces, under the ice of existing glaciers. It is of course impossible to conceive them to have been shaped and grooved simply by the friction they would have suffered in descending by gravity down the slide among the other débris.

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the summit; and 5,215 — 1,106 = 4,109 feet, the height of the given point of the ridge above sea level. It was *below* this point, it will be observed, that De Laski found his "upper fossils."

* Prelim. Rep. Nat. Hist. and Geol. of Maine, p. 395.

All the facts in the case serve to indicate that the non-granitic material found upon the mountain is a portion of the so-called "northern drift," with the fact of whose distribution — not the manner — we are here concerned. But we may and must suppose that in the distribution the sides and summits of Ktaadn, as far up at least as 4,600 feet, received deposits of drift more or less in quantity. Through the action of gravitation the slopes have become loaded with fragments of granite that have been wedged from its mass by frost. Ktaadn has thus been buried under its own ruins, and beneath these ruins has been hidden the drift that was deposited when the mountain was comparatively intact. The avalanches which have produced the slides have brought to light along their course the covered drift. Near the starting-point of the descent, where the movement was superficial, little or none of the hidden material has been unearthed; but farther down, where the avalanche ploughed deep, more was brought to the surface. The shorter East Slide, therefore, which is superficial in comparison with the other, shows far less drift than does the Southwest Slide; while Avalanche Brook, which flows over the steepest of the lower slopes, reveals in its deep channel more of drift than has elsewhere yet been found upon the whole mountain. There is reason to think that the bed of another stream, that runs on the north side of the East Spur, will, if followed up, yield like testimony.

But while proofs of the former presence of an ice sheet upon Ktaadn are so scanty and questionable, seeming indications of local glaciation are not wanting. The location and surroundings of three little ponds, that lie just without the mouths of the basins, are at least significant. Their waters are retained in place by low, irregular ridges, situated just where terminal moraines of glaciers issuing from the basins would naturally occur. Those that hem in the second and third ponds, counting from the outlet of the chain, on the supposition that they are moraines, must have been deposited by glaciers that moved down from the North Basin. The ridges that hold the first pond, and separate it from the second, would seem to have been supplied by a glacier from the South Basin. Entirely satisfactory determination of the nature of these ridges is impossible while they are, as at present, completely masked by dense thickets; but should fire hereafter lay them bare, opportunity will be afforded for thorough examination before a new growth springs up.

The outlet of the first or lower pond is cut to the depth of about twelve feet, through a ridge of débris that appears to be the continuation of the one which runs along the eastern margin of the same pond; and there can be but little doubt that the loose structure observed at the outlet prevails through the whole length of the retaining ridge. But as a running stream can speedily change stones over which it passes from irregular and angular forms to rounded and smoothed water-worn pebbles, such as now cover the surface at the outlet, no proof that the material of the ridge has the characters of a moraine deposit is attainable till an amount of digging is performed for which we had neither time nor tools.

Half a mile from the point last named is a little bog, fifty by one hundred feet in extent, represented in the heliotype as a faintly drawn pond. Going outward from the basin, one steps from the surface of the bog directly upon the foot of a narrow ridge, which rises abruptly to the height of twenty feet, and as abruptly falls off on the opposite side to a level much lower than that of the bog. Its relations to the adjacent heights favor the view that it is the terminal moraine of a glacier that came down a wide depression of the mountain side, between Pamola, the "Horseback," and its flat-topped branch. The hollow is widest and steepest above, and would constitute a promising gathering ground for a glacier. So far as could be ascertained, without extensive digging, the elevation apparently consists of loose material, which might be regarded as moraine débris.

Higher up in the same hollow, and nearly at the end of the flat-topped spur, is another diminutive pond, nestled behind what looks from a distance like the remnant of a moraine deposited later than the one below, and of which the greater part has been removed by denudation. These ponds will forcibly remind one who is acquainted with Viollet-le-Duc's "Mont Blanc" of the small lakes held in place upon that mountain by like ridges, which are described as undoubted old moraines.

The mouth of North Basin is shut across by a low hill, to be seen in the heliotype. Viewed from the northern summits, it seems to be the last deposited terminal moraine of a glacier which once occupied that basin; but on closer inspection its aspect changes, and it is to be regarded only as a possible, not a probable moraine. And, indeed, as is implied in the foregoing statements, the moraine-like form and location of the elevations which have been considered should be held, prior to thorough investigation, as indications that they may be, rather than proofs that they are, deposits from local glaciers.

Whether the depression on the northern side of the "Horseback" was, or was not, the track of veritable glaciers of a former period, it is now occupied at intervals by moving masses that approach as nearly to the character of glaciers as changed climatic conditions permit. The hollow is so broad, comparatively shallow, and smoothly concave in outline, that it cannot have been fashioned by running water, which on Ktaadn leaves its mark always in deep and narrow gorges. At about the middle of the concavity an open strip, ten or twelve rods wide, and completely cleared of trees, runs down the slope, for more than a mile from the bare upper mountain, through thick woods below. The growth, at the intermediate point where we struck the strip, is one of spruces twenty feet high, that rise like a wall on either side of the square-cut opening; while the strip itself is covered with growing bushes that averaged, last September, less than five feet high. Among the bushes lay prostrate, with their tops pointing down hill, small spruce trunks, bleached and dry, and evidently for some years dead. None of them were more than ten feet long. The dead trunks had been simply broken near the ground, and still lay attached to or near their bases. That the movement which cleared the strip is one that occurs only at intervals of some years, is proved by the considerable size the trunks had attained before they were broken down; and that at least one descent had taken place since that which felled them is shown by the fact that the eastern border of the strip, for a width of two rods, was free from bushes, but was covered with levelled spruces as large as those of the adjacent wood, and still retaining their branches and bark in nearly fresh condition. Here the thickness of the trunks was so great that they were not broken, but the roots were torn from the scanty soil on the upper side, leaving in the earth those that extended in the downhill direction. The mass that last descended was two rods wider on the east than any other which for many years had passed down the path. It must have levelled, for the time being, the bushes, whose elasticity saved them from breaking, and restored them to the upright position.

The inclination of the hollow, through its wooded portion, is moderate for Ktaadn. It is evident that snow, accumulated on the bare and steeper slopes above, under conditions that have recurred only after periods of some years, has swept down as an avalanche with an impetus that bore it far over the forest-obstructed smaller slope below.* In its progress it has successively prostrated, buried, and passed over the opposing small trees, in no case, at the intermediate part which we saw, carrying away the trunks or branches.

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* Under peculiar conditions, a trifling slope may serve, not only for the transmission, but for the origin of an avalanche. In Augusta a street, 100 feet wide, runs west from the river directly up the terraces before described to the general level

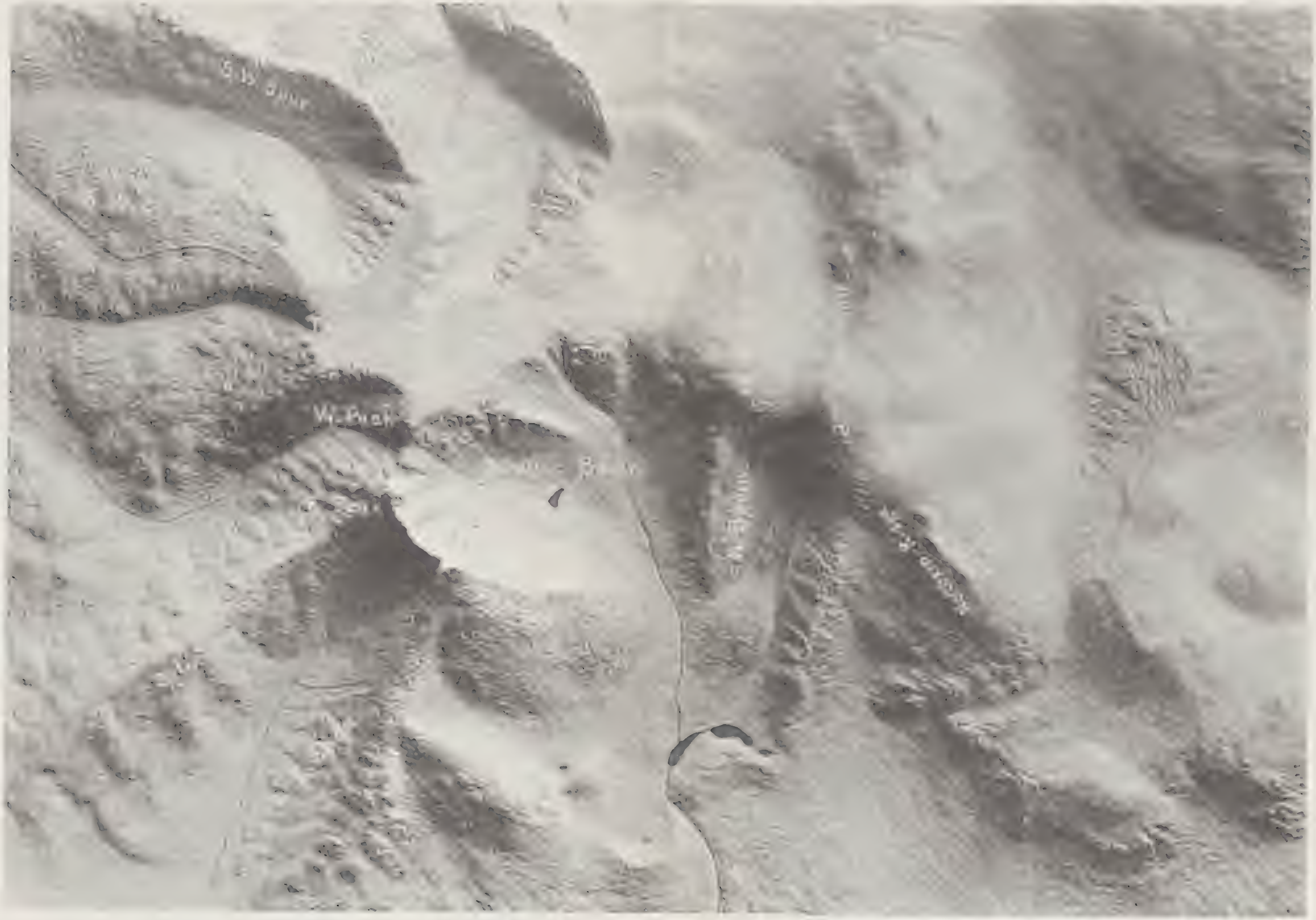
Certain huge blocks of granite that lie on the floor of the South Basin have been regarded by some as erratics, but in fact are parts of the adjacent cliffs, and owe their present location indirectly to the agency of ice. They are fragments of the eastern wall, which, falling upon inclined planes of compacted snow or ice accumulated in winter against the basin sides, have slid or rolled several rods beyond the great talus, 350 feet in height. Lying so far beyond the talus, which is the receptacle of most descending fragments, they have been mistaken for erratics, notwithstanding their agreement in composition with the nearest cliffs. In the same way alone can we account for the presence of great rock masses at stations so far out from the northern foot of Pamola that they cannot be supposed to have rolled thither over any other surface than an inclined plane of ice. Here, too, somewhat west from where the foot of the cleared strip must be, are four approximately parallel ridges made up of granite blocks of all sizes. They are of considerable length, and have between them hollows fifteen or twenty feet deep and some rods wide, but of unequal width. They appear too recent, — resembling parallel tali of fresh material, — and too near together, to correspond to my notion of old terminal moraines; and I was unable to explain their origin in any way satisfactory to myself.

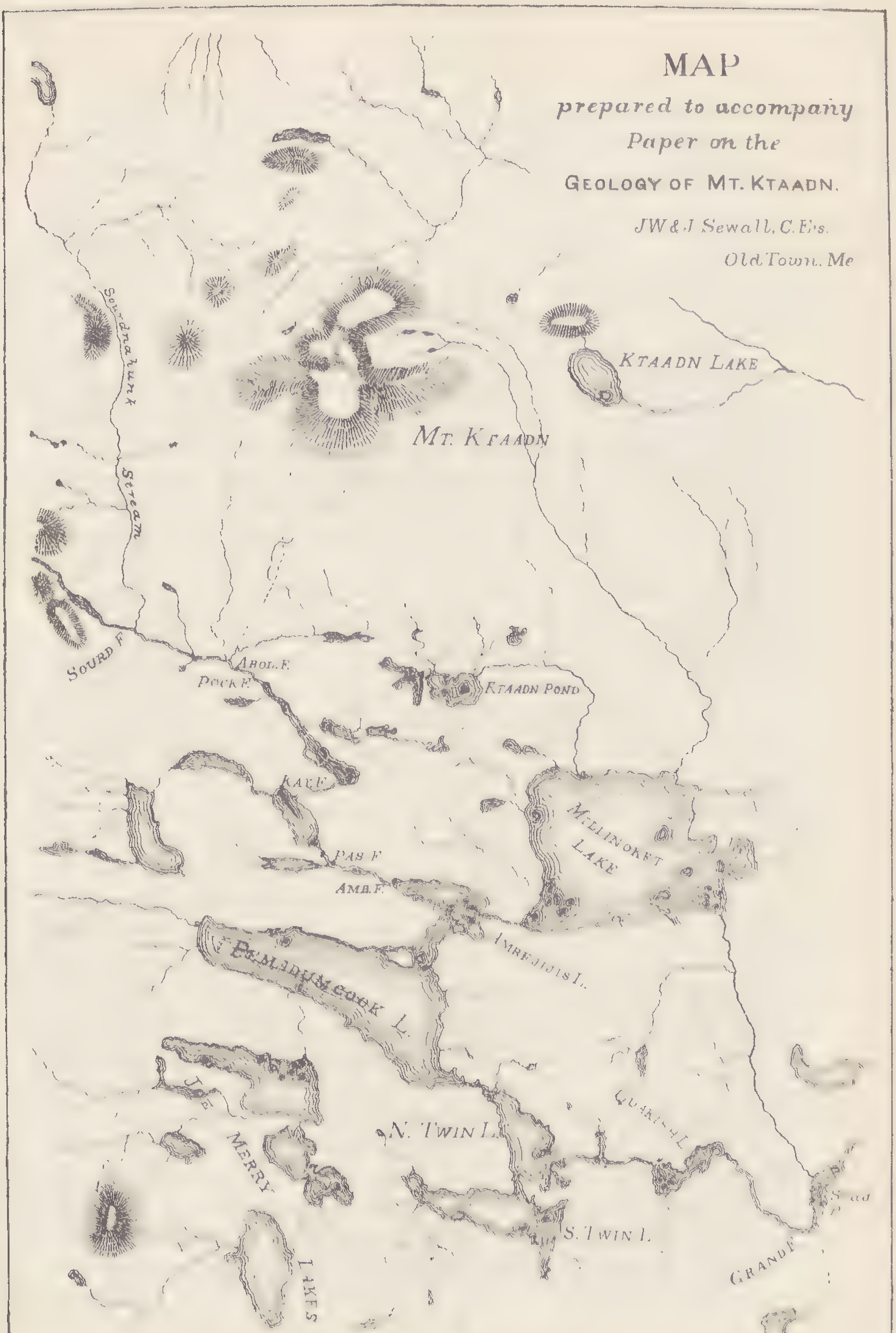
A change that was produced in a part of the southern lobe of South Basin, during the early summer of last year, is instructive, as illustrating the origin of the Ktaadn slides. The gorge between the Chimney and the peak of Pamola — a typical instance of erosion — is a deep and narrow cut, forty feet wide at its head, diminishing to ten at the foot, and upon its floor to two or three feet at the outlet, where it is a polished, concave water-course worn in the solid rock. Its small drainage area, and evidence derived from the accumulations about its foot, show that even in times of flood it ordinarily carries a stream of but moderate size. In the summer of 1879 the débris that had been brought down in a series of years extended downward from the foot in the usual fan-shaped "cone

above. The hillside from the upper terrace to the top is 1,300 feet in length. The inclination of the street near the summit is 11°; midway, 7°; below, from 3° down to 0°. Early in the winter of 1878–79, the snow, after continued rain, assumed the slushy state, and, starting from the middle of the hill, where the inclination is only 7°, rushed suddenly down the street with a roar, and piled itself on the level ground at the foot. On the steeper upper half the snow lay unmoved. In the ninety years since the street was opened, this is the only case of the kind recorded.

of dejection," rendering passable the portion it overspread of the talus, which, except at like places, is almost inaccessible from its base, being there made up of huge blocks like "monolithic houses tumbled together by an earthquake." The cone was furrowed by no deep channel, such as would have been formed had a large and powerful stream passed over it. In September last the whole had been changed. Without pausing for details, it is enough to say that a gully had been cut to a depth of fifteen feet, down which, at a quarter of a mile's distance, was piled, twenty feet high, a heap of bowlders, varying from ten feet in diameter down to those of moderate size, all mingled with earth and gravel. Here the first rush of water which effected the change was checked, and its course deflected. Lower down, smaller blocks were distributed in the order of their size; then came cobbles, next pebbles, then gravel, till at the distance of more than half a mile, and near the Basin Pond, one stepped suddenly down from a square-ending sand terrace two and a half feet high. Such an exhibition of material assorted by water, within so small a space, is rarely to be seen. A water-spout, or "cloud-burst," upon the peaks had wrought the havoc. It must have been confined to a narrow area, for signs of disturbance were wholly wanting on the talus half a mile north; and in the bed of the torrent, less than a mile distant, which descends from the Saddle and was both years our daily route from camp at the Basin Pond to the summits, no change from the previous year had happened. The time of the occurrence was fixed by valid proof. Scrub birches were found in the course of the flood completely stripped of bark, but often retaining at the tips of their highest twigs shrivelled leaves, which showed by their thinness that the shrubs had been torn from place just as the leaves were fully expanded.

Heliotype taken from a model of Mt. Ktaadn, representing the upper three thousand feet of the mountain, and an area of about ten miles in length by seven in width. The vertical scale of the model is three times greater than the horizontal. Lack of shade renders some of the features indistinct.





MAP
prepared to accompany
Paper on the
GEOLOGY OF MT. KTAADN.
JW & J Sewall, C.E's.
Old Town, Me

Sourdnahunk Stream
Mt. Ktaadn
Ktaadn Lake
Sourd F
Abol F
Pock F
Ktaadn Pond
Kat F
Pas F
Amb F
Millinoket Lake
Pemadumcook L.
Imbezijis L.
Joe Merry Lakes
N. Twin L.
S. Twin L.
Quakish L.
Grand F

No. 6. — *Report on the Recent Additions of Fossil Plants.* By LÉO LESQUEREUX.

IN the department of Paleophythology the collections of the Museum have been this year greatly increased by the following contributions: —

1. The Smithsonian Institution has presented one hundred specimens of tertiary and cretaceous plants, obtained by the U. S. Geological Surveys of the Territories under the direction of Dr. F. V. Hayden. They are referable to species published in the Cretaceous and Tertiary Floras, Vols. VI. and VII. of the U. S. Reports.

2. More than six hundred specimens of cretaceous fossil plants have been obtained in the Dakota group of Kansas by Mr. Charles H. Sternberg. These specimens, in a remarkably good state of preservation, represent forty specific forms, of which about twenty are new, and six known only as yet by the descriptions of Professor Heer.

The new species are referable, like those published already from this formation, to all the essential divisions of the vegetable kingdom. The Cryptogamous have fragments of a *Jeanpaulia?* and of an *Equisetum.* The Conifers are represented by a large *Thuites;* the Cycadeæ, by three or four species of *Podozamites.* The Phænogamous *Apetaleæ* have a *Myrica*, an *Alnites*, a *Quercus*, two species of *Ficus*, and a *Laurophyllum;* the *Dialypetaleæ*, an *Aralia*, three distinct forms of *Araliopsis*, a *Cissus*, four species of *Liriodendron*, an *Anona*, a *Greviopsis*, a *Sapindus*, and a *Rhamnus.* Besides these new species there are in the collection specimens of *Populus litigiosa*, *Ficus primordialis*, *Diospyros primæva*, already described by Heer from the Dakota group, with *Proteoides lancifolius*, described by the same author from the European Cretaceous of Quedlinburg, and *Magnolia speciosa*, from that of Moletin. Some other very rare species, like *Populites elegans*, *Platanus primæva*, *Magnolia tenuifolia*, *Liriodendron giganteum*, *Aralia Towneri*, *Aralia saportanea*, divers species of *Protophyllum*, and especially *Aspidiophyllum trilobatum*, are represented also by numerous beautifully preserved specimens. Taken all together, this collection is therefore a valuable acquisition for the Museum.

It is not less valuable in regard to the data which it affords in confirmation or contradiction of some of the general conclusions derived from the examination of the materials formerly described from this peculiar cretaceous flora.

For example, the disconnection of the flora of the Dakota group from that of the older ones, those of the Jurassic times, does not appear now as positive as formerly, or as it was indicated in the Cretaceous Flora, Vol. VI. of the U. S. Reports. For besides the *Pterophyllum* described in that volume as somewhat doubtfully referable to the Cycadeæ, plants which essentially constitute the vegetation of the Jurassic, we have now four species of the genus *Podozamites* either identical with or closely related to species known from this formation.

Per contra, the disconnection of the Cretaceous flora from that of the lower Tertiary appears now still more evident, as the new species do not indicate any affinity to the plants of the Laramie group, which is positively Eocene by its types. As yet no vegetable remains distinctly referable to Palms have been found in the Dakota group.

The vegetation of the Cretaceous seems to be essentially composed of synthetic types, genera or groups of plants of analogous characters, which it is extremely difficult to define and separate into species. And nevertheless, when considered separately, the leaves, which are as yet the only organs obtained for analysis, show points of difference so marked that it is not well possible to consider them as representing mere varieties. To prove this assertion, it is sufficient to examine the so-called species described under the generic names of *Populites*, *Platanus*, *Araliopsis* (a new division which includes most of the leaves described as *Sassafras*), *Aralia*, *Protophyllum*, *Menispermites*, etc. One of these types, however, the more peculiar and distinctly cretaceous in its facies, *Liriodendron*, was until now represented by few diversified forms, and therefore considered as simple, and the supposition seemed confirmed by its passage, with *Platanus*, *Sassafras*, and *Fagus*, through all the geological ages from the Cretaceous to our time, with scarcely any modifications and few representatives. But now the collection of Mr. Sternberg eliminates this exception, as we find in it four new and very distinct forms of this group, besides a beautiful entirely preserved leaf of *Liriodendron giganteum*, which had been described from a mere lateral lobe, and which was therefore of uncertain attribution.

A short description of this genus, and of its species as exposed by the leaves, may show how uncertain, though binding, are the characters of the Cretaceous leaves.

GENUS *Liriodendron*. Leaves panduriform, oppositely bilobed ; lobes oblique or in right angle, obtuse or acuminate ; midrib thick ; lateral veins in right angle, opposite or irregularly alternate.

1. *L. giganteum*. Leaves large, twenty centimeters broad between the lower broad (six centimeters), oblong, obtuse or rounded lobes ; upper lobes shorter, slightly turned upwards, narrowed and rounded to an obtuse point, joining the lower in an obtuse sinus at a short distance (two centimeters) from the medial nerve.

This form is the one more distinctly related to *Liriodendron tulipifera*, the species living at our epoch. It cannot be considered identical with it, however, the difference in the characters of the leaves being too marked, but not more so than in the following forms, which I consider as new species.

2. *Liriodendron acuminatum*, sp. nov. Leaves small, about half as large as in the preceding species, cut in two pairs of narrow linear acuminate lobes, about one centimeter broad, all curved upwards.

3. *Liriodendron cruciforme*, sp. nov. Leaves large, upper lobes broad, square or equilateral, in right angle to the broad midrib ; lower lobes narrow, linear, acuminate, much longer and turned upwards. The shape of the leaves is like that of an anchor, except that the medial nerve or axis does not pass above the upper borders of the lobes.

4. *Liriodendron semi-alatum*, sp. nov. Leaves divided at the base in two opposite short rounded lobes (one on each side) curving up to near the medial nerve and then enlarging upwards into an obovate or spathulate entire lamina.

5. *Liriodendron pinnatifidum*, sp. nov. A single leaf with the general facies, and the venation of a *Liriodendron*, but subalternately trilobate on each side. The top of the leaf is broken.

Besides the above forms, there have been described already, from the Dakota group, *Liriodendron Meekii*, Heer, a species with comparatively small leaves, only three to five centimeters long, two to four centimeters broad, the lobes equal in length, short and rounded ; and *Liriodendron primævum*, Newb., from a leaf of which the upper half is destroyed, and whose characters are not sufficiently defined. By the size of the leaves, the species is intermediate between *L. Meekii*, Heer, and *L. intermedium*, Lsqx. ; form also known from a single lacerated leaf, which, narrow in the middle, has long obtuse lobes turned upwards, and a facies different from that of any of the other forms described. We have thus eight specific forms of leaves representing the clearly defined type or genus *Liriodendron*, all differing so greatly that it is not possible to consider them as mere varieties of one species only, and nevertheless of characters so closely allied that their specific identification seems to be hazardous. And this, as said above, is the case with most of the so-called species of the Dakota group.

The difficulty is increased by the fact that by gradual modification the leaves pass to evidently different generic types. The genus *Liriophyllum*, for example, represents leaves of *Liriodendron* nearly round in outline, but split at the top and to below the middle in two lobes joined in a narrow sinus upon the medial nerve, a peculiar division and facies which have no analogy in any species of plants of our epoch. This new genus is by its leaves intermediate between *Liriodendron* and *Populus*.

The local distribution of the leaves may be relied upon to give some directions for the separation of species. For of course if the analogous forms are found in separate and distant localities, the marked differences are more likely to be specific. On this subject the specimens collected by Mr. Sternberg afford good opportunity for examining the question. Omitting details, it suffices to mention what is known of the distribution of the leaves of *Liriodendron.*

L. Meekii is described from specimens found in Nebraska and Minnesota only. The specimen of *L. primævum* is labelled Blackbird Hills, Nebraska. This form is allied only to *L. semi-alatum* of Kansas. *L. intermedium* is also from Nebraska, represented in one specimen only, and has no affinity with any of the Kansas species. *L. giganteum* was first described from a fragment found near Fort Harker, Kansas, while the specimen of the Museum is from two and a half miles from Glascoe, in another county, where also were found *L. acuminatum* and *L. pinnatifidum*, whose leaves have little affinity of characters between them. *L. semi-alatum* was found at a different locality seven miles distant from Glascoe, and *L. cruciforme* at Elkhorn Creek, twelve miles northwest of Ellsworth.

From this kind of distribution it seems legitimate to conclude, not only for *Liriodendron*, but also for all the other groups of this flora whose leaves present the same degree of affinity or of difference, that, if the forms are derived from synthetic types, and if they are found somewhat modified in characters at distant localities, it is a proof that the modifications are already fixed, have become local characters, and that they may be considered as specific.

On another question, that of the derivation of the vegetable remains found in the strata of the Dakota group, and of their distribution, either in place, from trees grown there, or as transported by water from distant localities, a question examined already in the Cretaceous Flora, the collection of Mr. Sternberg affords the same degree of evidence as for the preceding.

It has been observed in the Flora, Vol. VI., *loc. cit.*, that the Cretaceous leaves and other remains of plants are found always spread over small areas, generally less than one or two acres in surface, and far distant from each other, so that in travelling over the prairies of Nebraska and Kansas, the collector may wander for twenty to forty miles or more without discovering a single fragment of fossil vegetable, and abruptly come to one rich deposit where leaves are found in abundance. Generally each of these deposits has remains of plants of a peculiar group, even sometimes of a single species. For example, *Aspidiophyllum* leaves are from one place only; *Aralia Saportanea,* from two widely distant. *Protophyllum* and *Sassafras,* or *Araliopsis cretaceus,* and its varieties, abound at Thompson's Creek, while species of *Salix* and *Podozamites* are from Elkhorn Creek and Glascoe; and so on. The localities where the specimens examined were found are twenty in number, and in each of them only two to a dozen species have been recognized. A grouping of this kind shows that the leaves were derived from trees grown in place where the leaves are now found, the trees apparently covering hillocks, or dry surfaces of land, disseminated in wide lagoons. As floated from a distant shore, the leaves should be more or less, but always, mixed. Their fine state of preservation, their position generally flat, confirm this supposition.

3. A second lot of specimens from the same formation has been procured for the Museum in Colorado, near Morison, by Rev. Arthur Lakes. The number of specimens is small, and the species which they represent are all, except one, already known from the Dakota group of Kansas. Among them are *Proteoides grevilliæformis, P. daphnogenoides, Magnolia alternans, M. Capellini,* described by Heer in the Phillites of Nebraska, *Sassafras cretaceus,* Newb., *Salix proteæfolia,* with *Liriophyllum populifolium, L. Beckwithi, Aralia Towneri, Sterculia lugubris,* and species of *Ficus,* most of them found in Kansas, and already figured for the eighth volume of the U. S. Reports. One of the species only, a peculiar small form of *Liriophyllum,* is new.

4. The last addition of this year to the phytopalæontological department of the Museum has been made by the acquisition of nine hundred specimens of coal plants from Mr. I. T. Mansfield of Cannelton, Pennsylvania. This locality has until now furnished to the coal flora an abundance of vegetable remains of species rarely found elsewhere. Of the genus *Cordaites,* for example, formerly known by separate leaves or mere fragments of leaves only, specimens have been found there with branches bearing leaves, and even flowers and fruit. A proportionately large number of specimens of this kind are in the Cannelton collection,

which represents fifty species, mostly in finely preserved materials. Among the species worth mentioning are *Odontopteris cornuta, Callipteridium inæquale, Alethopteris ambigua,* divers species of *Stemmatopteris* and *Caulopteris, Lepidostrobus spectabilis, Lepidophyllum Mansfieldi, Sporocystis* and *Lepidocystis* species, *Tæniophyllum decurrens, Rhabdocarpus Mansfieldi,* all peculiar to the locality, or not as yet found elsewhere, and splendid and numerous specimens of the rare spikes of *Macrostachia infundibuliformis, Neuropteris cordata?* Brgt., or *Cyclopteris trichomanoides ?, N. heterophylla,* Brgt., *Pseudopecopteris Pluckneti,* and *P. anceps;* many specimens of *Spiropteris,* circinnate branches of ferns (spirally coiled inward in the process of unfolding), of *Sigillaria monostigma,* of *Artisia* (decorticated stems of *Cordaites*), of *Cordaianthus* (their flowers), of *Cordaicarpus* (their fruits), etc. As the Museum had not any specimens of that peculiar locality, these plants constitute an important addition to the collection.

With the materials obtained this year the Museum has now in fossil plants: —

1. From the Devonian, a series of specimens presented by Professor J. W. Dawson and Mr. C. T. Hartt from the measures of Canada, and from England a number of very fine ones, presented by Sir Charles Lyell. Among these is a splendid fruiting pinna of *Archæopteris Hybernica.*

2. From the Carboniferous, a large number of the best specimens found in the nodules of Mazon Creek, the shales of Morris, and other localities of Illinois; numerous and good specimens from the anthracite basins of Rhode Island and of Pennsylvania; fine materials from divers localities of Ohio and Kentucky, presented by Mr. Anthony; rare specimens from the subconglomerate measures of Ohio and Tennessee; and the collection of Cannelton mentioned above.

3. From the Cretaceous of the West the Museum has now an amount of materials sufficiently representing the Dakota group. Fine and numerous specimens can be spared for exchange.

4. The Tertiary of this continent is insufficiently represented in the Museum by a number of specimens presented by the Smithsonian Institution, and by a few sent by Rev. Arthur Lakes from Golden, Colorado. There is, *per contra,* from Europe a splendid collection of Miocene plants purchased from Professor Heer, of Zurich, and a number of undetermined specimens from divers formations and localities, mixed with animal remains, in the collection of Bronn.

No. 7. — *The Great Dike at Hough's Neck, Quincy, Mass.* By John Eliot Wolff.

This dike is situated some two and a half miles northeast from Quincy Depot; rising, when first seen, as an irregular ridge, and continuing, with interruptions, for about a mile in an easterly direction.

Mr. Crosby has mentioned this locality in his "Contributions to the Geology of Eastern Massachusetts": * — "On Hough's Neck, in Quincy, the amygdaloid is a green, slaty rock; it is sometimes amygdaloidal, and sometimes porphyritic, and includes masses which resemble felsite. It occupies the axis of an anticlinal in the conglomerate; and also cuts the latter rock very freely, after the manner of an eruptive." (p. 176.) Again: — "On Hough's Neck, in Quincy, along the north side of Rock Island Cove, there are prominent ledges of conglomerate flanking a large mass of amygdaloid, and the latter rock crops through the former in isolated bands, due to extravasation or faulting. The conglomerate strikes about east-west, and shows nearly vertical dips to the north and south, dipping away from the amygdaloid. It holds unmistakable pebbles of Shawmut breccia. This is clearly a faulted anticlinal fold. Toward the north, over the area marked as slate, the rocks are all concealed by drift; but on the south the conglomerate shows very plain indications of a passage to slate." (p. 209.) The amygdaloid, constituting a member of Crosby's Shawmut group, is regarded by him as older than the overlying Primordial conglomerate, and as a sedimentary rock in general, though sometimes presenting evidence of intrusion.

The country rock of the dike is a coarse conglomerate, with occasional interbedded layers of red sandstone and slate. At the eastern end it is bordered on both sides by the conglomerate. After running for a quarter of a mile as a ridge, the dike suddenly loses its ridge character, and occasional exposures only are found in the field to the east, among the outcropping conglomerate ledges. It can be traced thus for a quarter of a mile; then for some hundred feet no outcrop of dike is found until a small creek is reached. Crossing this, however, we again find a dike continuing as a ridge in the same direction for some hundred yards, when it disappears under the drift of a headland. This exposure, however, is not in the line of strike of the main, or westerly part of the dike, but lies some hundred feet to the north. Whether this change is due to a horizontal throw, or to a fresh outbreak of dike along a parallel line, does not appear.

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* Occas. Papers, Bost. Soc. Nat. Hist., III., 1880.

At the western end, on the southern side, the junction with the conglomerate and red sandstone is very irregular, — large and small tongues of the dike penetrate into the conglomerate, this rock having a strike N. 60°–80° W., and a dip 70° south. The junction between the two rocks is sharp and well marked : the dike seems often amygdaloidal near the junction. Sections of the contact of the two rocks show that the dike is composed of a mass of very small feldspars, having a beautiful fluidal arrangement, while they are often bent when in contact with the line of the conglomerate. On the northern side, a fine vertical exposure of the junction is obtained, which is seen to stand almost vertical ; the dike cutting the slate and conglomerate a little irregularly, but standing nearly parallel to the stratification. The conglomerate here is nearly vertical, but may be said to dip to the north very steeply ; if, however, we pass east along the strike, a few hundred yards, to the exposures in the field, we find that all the conglomerate, both north and south of the line of the dike, dips steeply in one direction, i. e. south. I cannot, therefore, agree with Mr. Crosby, that "this is clearly a faulted anticlinal fold." It may equally well be an intrusion of the dike into the vertically standing strata, causing irregularities of the dip. More detailed study is required. In the western ridge the dike has a width of about three hundred feet from contact to contact.

The rock is generally of a greenish color, approaching a greenish red in the fresher portions ; it is irregularly jointed. In texture there is great variation between coarse, fine, porphyritic, and amygdaloidal. Masses of quartz, and yellowish-green epidotic material frequently occur. These greenish masses are often very irregular, occasionally vertically banded, and resembling fragments of a stratified rock, and often lined on the exterior with a band of reddish substance. Microscopic sections of some of them give a mixture of quartz, calcite, epidote, and a whitish opaque substance (kaolin ?), and show that they are in part areas in the rock of decomposition, or segregation.

Although at first sight this dike appears to be a homogeneous mass of rock, yet it is in reality composed of rocks belonging (in all probability) to at least three separate eruptions, forming, instead of one, numerous dikes. To this fact is largely due the noticeable variations in the area of rock. First in order comes the amygdaloid, forming the principal mass of the rock, and eruptive through the conglomerate. In the second place, a close study of the great area of this rock shows that it is cut by a large number of narrow diabase dikes, generally but a few feet in width (e. g. three feet), which do not have a marked amygdaloidal structure. In many cases they run almost parallel with the trend of the amygdaloid; in other cases they run obliquely, while others again may cut almost transversely across it, in parallelism with a third dike to be mentioned. These dikes show generally well-marked contacts with the amygdaloid: they are fine-grained at the junction, but coarse-grained in the centre; in some cases they have melted the amygdaloid at the contact, so that it is difficult to find the actual line. Some of them are easily distinguished from the amygdaloid, under the microscope, by the large amount of augite which they contain, but in others this mineral cannot be found as such, for all trace of it (if originally present) has been lost in the alteration products. Lastly, about the middle of the large western exposure of the amygdaloid there is found a large dike (at least seventy feet wide) running transversely across it, in a direction N. 5°–10° W. On the south side it is seen breaking through the conglomerate and sandstone, and can be traced from that locality across the amygdaloid. No exposure was found giving the actual contact of this rock with any of the others, although it can be seen at a distance of a foot or two from them. Judging from its direction, which cuts directly across the trend of a great number of the small dikes, it would seem to be the latest rock of all. Some of the small dikes to the east of it are, however, nearly parallel with it. While, therefore, there seem to be at least two periods of eruption subsequent to that of the amygdaloid, yet some of these small dikes may cut the others, thus complicating the phenomena still further. I have not been able to find evidence of this beyond the difference of direction; and to settle the question by the discovery of the actual contacts will be difficult, on account of the lithological similarity of all the eruptive rocks, and the thick covering of lichens, which conceals everything, and makes any work there laborious.

The amygdaloid sometimes loses its amygdaloidal character, so as to resemble greatly the later dikes; but in such cases the passage is gradual.

The microscopic descriptions which follow show that all these rocks are altered basalts, and, together with the field relations, prove that they are all truly eruptive rocks, breaking through the conglomerate, while the later eruptive rocks cut the earlier ones.

[1.] *From Western End of Dike, North Side, near the Road, — one of the small Dikes in the Amygdaloid.*

Lens. A greenish-gray, felty-looking rock, containing minute grains of pyrite, and small feldspar crystals. Traversed by veinlets of epidote. — *Section.* White opaque feldspar crystals, and masses of opacite, magnetite, and pyrite, in a green chloritic groundmass. The feldspars have generally the long ledge form of the basaltic triclinic feldspars, but occasionally the form of Carlsbad twins of sanidin. They are entirely altered to a fibrous and scaly aggregate, polarizing with yellow and blue colors, — often with the brilliancy of talc. Colorless needles with cross fracture (apatite) occur occasionally in the feldspars, and also aggregate quartz. Between the feldspars lies a mass of green fibrous products, — chlorite, viridite, etc., considerable epidote, magnetite, quartz, etc., — rarely hematite and biotite. The magnetite often has the form of a grating, reminding us of decomposed olivine. The feldspars occasionally have a fluidal arrangement.

[2.] *Contact of Amygdaloid and Conglomerate at Southeast Corner.*

Section. A mass of small feldspar crystals, having a well-marked fluidal arrangement, and surrounding decomposed crystals of olivine and masses of magnetite and opacite. The olivine crystals have the characteristic lozenge shape, blackened border, and irregular fissuring, while the small parallel feldspars of the groundmass separate and flow around the crystals. Some are altered within the black border to a light green serpentine with fibrous polarization; in others, while the centre shows the brilliant polarization and the pitted surface of olivine (though the greenish color is evidence of some alteration), the exterior zone of the crystal has been altered to a bluish-gray substance, which in polarized light is seen to contain fibres with brilliant polarization, and may perhaps represent a stage in the alteration to talc. Some of the olivines are wholly or partially altered to ferrite and talc, the latter polarizing very brilliantly. Some of the magnetite and opacite in the section is derived apparently from the complete alteration of grains of olivine. The feldspars have generally the long ledge character of the basaltic feldspars, though some have the form and optical properties of Carlsbad twins. Occasionally there is found a crystal sufficiently fresh to show the multiple twinning, but generally they are filled with greenish or transparent scales, while along the centre of the ledge crystal there runs a line of green chloritic material, containing generally less opacite than the similar substances lying outside the crystal, but often continuous with them. Some of the crystals are more than half filled in the centre by a rectangular mass of this chlorite, often extending through to connect with that outside. The space between the feldspars is occupied by chloritic materials, opacite, etc., together with some quartz. Epidote and quartz occur in the groundmass as alteration products, and transparent needles, frequently broken across, which are probably in part apatite. Along the line of the conglomerate some of the feldspars are bent.

[3.] *West End of Amygdaloid very near* [1]

Lens. A gray-colored groundmass, containing white and greenish feldspar crystals, spots and crystals of epidote, occasional quartz and epidote amygdules, and reddish areas of decomposition. — *Section.* Composed principally of feldspars, with considerable epidote, chlorite, opacite, etc. The feldspars are mainly plagioclase, but there are occasional Carlsbad twins of sanidin. Some of the large porphyritic feldspars are broken and fragmentary; an effect, apparently, of the flowing base, for the small feldspars diverge, and flow around the large crystals. In some cases they are seen to have been pushed into the large crystals a certain distance on opposite ends along the central line, while a line of base passed through the crystal connecting the two tongues. This base, however, is now altered to calcite, chlorite, epidote, etc. Occasionally two feldspars interpenetrate each other. The products of their decomposition are the same greenish or colorless scales (which often have a brilliant polarization), epidote, chlorite, calcite, quartz, and colorless needles. The smaller feldspars seem less decomposed than the larger ones. Between the feldspars lie masses of chlorite, epidote, opacite, calcite, magnetite, etc.; often in the form of wedges between the diverging feldspars. One grain of altered olivine is seen in the section, identified by the shape and the previously described motion of the groundmass and base around it. The exterior consists of reddish ferrite, penetrating along the fissures; the interior of quartz.

[4.] *West End of the Amygdaloid near* [1] *and* [3], *but nearer in the Centre of the Mass.*

Lens. Similar to [3]. — *Section.* The large feldspars are broken by the base, as described above. Plagioclase and sanidin occur. True amygdules occur here, recognized as such by the regular shape, and by the fact that the small feldspars of the groundmass flow around the cavity and are distinctly separated from it. They are filled with epidote, chlorite, calcite, quartz, and a fibrous chalcedonic (?) material: the epidote is generally on the outside, the chlorite inside. Considerable epidote is scattered through the section, generally outside of the feldspars, and also talc, calcite, and quartz. These decomposition products often occur in the groundmass in rounded areas, but are not true amygdaloids. Patches of reddish opaque ferrite also occur in a similar manner, constituting the red spots seen macroscopically.

[5.] *Western Ridge of the Dike on the West Side of a Road which crosses it, — taken towards the Centre of the Mass.*

Lens. A greenish groundmass containing porphyritic feldspars, reddish and greenish areas of alteration, and rounded masses of quartz. The groundmass has intruded into some of the large feldspars. — *Section.* Crystals of feldspar and areas of decomposition or infiltration surrounded by a greenish chloritic mass. The large feldspars are occasionally Carlsbad twins; the small ones of the groundmass principally plagioclase, although some are twinned sanidin crystals. The (original) base, carrying small feldspars, has bent some of the large feldspars, and pushed into them. Others contain in the centre square zonal inclusions of the greenish mass, while the outer zone of the crystal is free from it. These phenomena are similar to those so frequently observed in the unaltered basalts with a glassy base. Many of the larger feldspar crystals are partly filled with epidote grains, chloritic material, and light-green needles, which have a yellowish-white polarization. Rounded areas, composed of greenish chloritic fibres, with sometimes a deep violet blue color between crossed nicols, occur in the groundmass, mingled occasionally with talc, and bordered by epidote. Some of these areas, enclosing the remains of the small feldspars, arise from the decomposition of the groundmass; others are either true amygdules, as described above, or some might be pseudomorphs after some mineral, — for instance, olivine. Between the feldspars lies the green mixture of chlorite, viridite, and greenish needles similar to those described in the feldspars, beside some epidote, calcite, and quartz.

[6.] *Western Ridge of the Amygdaloid, about fifty feet east of a Road crossing it, — the Specimen taken from a long Dike crossing the Amygdaloid obliquely to its Main Trend.*

Lens. A grayish-green groundmass, holding crystals of greenish feldspar and grains of pyrite. The groundmass has pushed into some of the long crystals. Powder feebly magnetic. — *Section.* Much decomposed. The feldspars retain their outline, but are filled with chloritic material, — kaolin, epidote, and calcite. Magnetite is very plentiful in crystalline and irregular forms, having often a whitish, decomposed surface (leucoxene), which, in connection with the reticular or branching shape of the masses, shows the presence of menaccanite. Pyrite occurs in occasional grains and square crystals, generally close to or mingled with the magnetite or decomposed menaccanite, and is therefore probably an alteration product. The remaining portion of the rock is a confused mixture of chlorite, epidote, quartz, viridite, hornblende, calcite, and colorless needles, in part probably apatite, — all products of alteration. This rock is the most coarsely crystalline and the most decomposed of any examined.

[7.] *From the Exposure of the Dike in the Field midway between the extreme Eastern and Western Ridges.*

Lens. Similar to the preceding hand-specimens, but rather reddish in color, and somewhat more amygdaloidal. — *Section.* A much fresher rock than those already described. The few porphyritic feldspars are generally plagioclase, and exhibit the same proof of an early crystallization mentioned above (i. e. the feldspars of the groundmass flow around them, etc.). The feldspars of the groundmass are principally plagioclase, but some Carlsbad twins and unstriated crystals can be found. All these feldspars are comparatively fresh, and the formation of the greenish scales and other products of decomposition has not progressed far. The frequent inclusions of the original base, however, are entirely altered to chloritic products and magnetite. The feldspars contain occasional large rounded or irregular fluid inclusions, with bubbles, and immense numbers of extremely small similar inclusions (requiring the use of powers of from 700 to 900) characterized also by occasional moving bubbles. Grains and crystals of epidote occur in the feldspars, and occasionally quartz. Chloritic products and magnetite represent the original base. Epidote occurs in the groundmass in patches; calcite is rare. True amygdules occur, filled with chlorite, quartz, and epidote.

[8.] *From the Ridge constituting the extreme easterly Exposure of the Dike, and not in Line with the Western Half, though trending parallel with it.*

Lens. A reddish groundmass, containing feldspar crystals, amygdules of greenish chlorite, and red spots resulting from the decomposition of the rock. — *Section.* The least decomposed rock of any examined. It has a groundmass composed of small ledge-shaped feldspars, magnetite, chlorite, epidote, etc., enclosing porphyritically a few large feldspars. The majority of the crystals are plagioclase, but there is a considerable number of Carlsbad twins. The small feldspars of the groundmass show the flowing of the base around the large crystals, as described previously. The larger feldspars contain very characteristic inclusions of a base in irregular, reticulated, or cylindrical forms. They often fill a large part of the crystal; may be zonally arranged; and are absolutely identical in shape and other characteristics with the inclusions of glass or base in the unaltered basalts. These inclusions are now altered to magnetite and greenish chloritic or viriditic products. Besides these dark inclusions of base, the feldspars are filled with almost colorless microliths and scales, — the products of the incipient decomposition of the feldspathic substance, — and very minute fluid inclusions, rounded, cylindrical, or branching. Some epidote and calcite occur in the feldspars. True amygdules are found, filled with calcite, epidote, and chlorite. Irregular masses of epidote occur as areas of alteration in the groundmass, — the magnetite often in large masses, enclosing the small feldspar crystals of the groundmass, and mixed with considerable ferrite. One decomposed crystal may perhaps be referred to olivine.

[Q. 8′.] *The Large Dike running nearly at Right Angles across the Trend of the Amygdaloid.*

Lens. A coarse-grained, dark green rock, containing crystals of feldspar, pyrite, magnetite, and hornblende, in a dark green groundmass. — *Section.* Contains (comparatively speaking) large-sized feldspar crystals; fibrous, greenish, dichroic hornblende; crystals of magnetite and pyrite; decomposed crystals of olivine; epidote; and viridite, quartz, apatite, etc. The feldspars are to a great extent kaolinized. The hornblende occurs in irregular masses, shows strong dichroism and brilliant polarization, and contains a great deal of epidote in rounded grains. Some of the feldspar crystals lie imbedded in the hornblende, or cross it, just as they do in the case of the augite of the less decomposed diabases, so that this and the whole character of the hornblende indicate that it is (in part at least) a product of the decomposition of the original augite. The olivine occurs generally in shattered crystals, with the usual blackened border. The interior is altered to greenish serpentinous products; but little spots still show the polarization and other characteristics of the unaltered olivine. The magnetite is found in extremely irregular forms, while the pyrite grains often contain magnetite, and therefore arise probably from its decomposition.

[Q. 1′.] *One of the Narrow Dikes running parallel with the Trend of the Amygdaloid.*

Lens. A compact greenish rock containing crystals of feldspar. — *Section.* Contains feldspar crystals, augite, magnetite, pyrite, and decomposition products. The feldspars are kaolinized, or else decomposed to white fibres, and contain considerable epidote, viridite, etc. The augite occurs in irregular masses ; it is reddish and has well-marked cleavage ; the decomposition to viridite, hornblende, and epidote is seen to be well advanced, these substances forming along the cleavage lines. The magnetite often shows the white decomposition characteristic of menaccanite. The pyrite is probably derived from the magnetite. No traces of olivine were seen.

[9.] *Section of Two Pieces of the Greenish vein-like or irregular Masses found in the Rock.*

One of the fragments is composed of epidote, calcite, quartz, and an opaque gray substance, perhaps kaolin, — mixed with the remains of feldspar crystals. The other fragment, from one of the banded veins, is composed of the same substances arranged in bands. Both are probably areas of decomposition in the rock.

Summary.

From the details given we obtain the following generalized description of the amygdaloid proper. In the hand specimens the groundmass varies in color from green, through gray, to red, — the last color characteristic of the rock that is least decomposed. It sometimes encloses large green or white feldspar crystals, often indented by the groundmass, or the feldspar crystals may be comparatively minute ; grains and crystals of epidote are occasionally seen. The rock generally contains greenish spots of epidote and of chloritic material, in part true amygdules, and spots of reddish decomposition. There are also amygdules of calcite and quartz.

The specimens from which the eight sections were made differ chiefly in the degree of decomposition, the presence or absence of olivine, and the coarse or fine texture. The specimens from the eastern end are much less decomposed than those from the western end.

As seen under the microscope, the rock is composed of large and small feldspar crystals, magnetite, epidote, calcite, and a mass of chlorite, viridite, and opacite. The large porphyritic feldspars are twinned plagioclase, and occasionally Carlsbad twins of sanidin. The minute feldspars of the groundmass flow around them, encroach upon, and sometimes break them. Rarely, the groundmass, holding small feldspars, has pushed into a crystal, a little distance on either side, and a tongue of the (original) base, alone, without the small feldspars, passes through the crystal and connects the two intrusions, — this connecting tongue now altered, however, to calcite, chlorite, and epidote. The small feldspars, when sufficiently fresh, show the triclinic twinning; but some Carlsbad twins of sanidin and unstriated crystals occur, the former of which cannot be referred to the plagioclase that, owing to the alteration, does not show its multiple twinning.

The degree of decomposition that the feldspars have undergone varies in the different sections: in the freshest rock they contain immense quantities of minute fluid inclusions, characterized by moving bubbles, and occasional larger ones, rounded or irregular in shape, together with inclusions of the base. The latter are cylindrical, or irregularly reticulated in form, often zonally arranged in the interior or exterior parts of the crystal; they are absolutely identical in shape, and in their relations to the enclosing crystal, with the inclusions of glass or base of the fresh basalts; they are now altered to magnetite, viridite, and other products. In the smaller feldspars these intrusions generally run through the centre of the crystal, parallel with the twinning-plane. Even in the freshest specimens, the substance of the feldspars is filled with minute microliths, and scales either colorless or of a light greenish color, with occasionally some epidote, calcite, or quartz, — generally products of the decomposition of the feldspathic substance proper. In the more decomposed specimens these products multiply, so that the crystals become a mass of these viriditic scales and fibres (often polarizing with the brilliancy of talc, or in red and yellow colors), or even of opaque kaolin, while calcite, epidote, quartz, and colorless needles with cross fracture, in part apatite, appear to a greater or less extent. The epidote occurs generally in the large feldspars in grains: some of it may originate from the alteration of included minerals; but of this there is no proof. Occasionally two feldspars interpenetrate each other.

The only other original mineral, unless it be part of the magnetite and apatite, is olivine. This was found in well-marked, large, and undecomposed crystals only near the contact of the amygdaloid with the conglomerate (described with section [2]); though what seemed to be the remains of olivine crystals were found in one or two other sections. Their relations to the groundmass prove an anterior origin: some of the magnetite and opacite in the sections have probably been derived from the alteration of small fragments of olivine.

Between the large and small feldspar crystals lies a mass of greenish alteration products, — chlorite (often dichroic), viridite, magnetite, opacite, considerable epidote, quartz, and calcite. When some of the large feldspar crystals diverge, the triangular space between them is filled with very small feldspar crystals, lying in this greenish mass; showing, as has been often remarked, that it is merely an original, glassy base, much altered, for we find this same relation in the unaltered basalts. Calcite, quartz, epidote, hornblende, biotite, apatite, etc., in the decomposed base, seem to belong to the more advanced state of decomposition.

Magnetite is always present. A large part of the magnetite arises from the decomposition of the base, and it is generally difficult to say what part of it is original.

While in some sections true amygdules are wanting, yet they generally occur, characterized by their sharp boundary, and the arrangement of the feldspars of the groundmass parallel to their outline. They are filled by epidote, chlorite, viridite, calcite, or quartz; the epidote generally on the outside, when other minerals occur with it. Besides these true amygdules, areas of decomposition occur in the groundmass, consisting either of opaque ferritic material, constituting the macroscopical red spots, or of epidote, chlorite, viridite, etc., enclosing the small feldspars.

Assuming that all the specimens described belong to the same rock-mass, this rock, according to the classification used, would be referred to both the Diabase and Melaphyr sections of the Basalts* (according to the specimen examined), or again might be called a Diabase and Olivine-diabase.† It is found by study to be a rock which, in the original state, was composed of the feldspars, olivine, magnetite, a base (glassy, microlithic, etc.), and probably some augite (though this cannot be identified now), all in varying proportions, and that these original constituents have been largely replaced by secondary products. It is therefore an altered basalt, as has been previously shown by others for similar rocks of this region.‡

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* M. E. Wadsworth "On the Classification of Rocks," Bulletin Mus. Comp. Zoöl., Vol. V. No. 13.

† Rosenbusch, Mikros. Phys. der Mass. Gest., etc.

‡ M. E. Wadsworth, Proc. Bost. Soc. Nat. Hist., Vol. XIX. p. 217 *et seq.*, 1877. E. R. Benton, Ibid., Vol. XX. p. 416 *et seq.*, 1880.

The examination of the sections made from some of the narrow dikes which cut the amygdaloid seems to show, in general, a similarity to either [Q. 1′] or [6] — one series containing undecomposed augite, the other none that can be identified. The great cross dike is described under [Q. 8′]. All of these later eruptive rocks seem in a more advanced stage of decomposition than the amygdaloid.

July, 1882.

No. 8. — *On some Specimens of Permian Fossil Plants from Colorado.* By Leo Lesquereux.

Last February, Rev. Arthur Lakes, of Golden, wrote me that he had found in South Park, near Fairplay, Colorado, a bed of shale with beautiful insect remains mixed with a profusion of vegetable fragments resembling the scales and seeds of Conifers, and with them some well-defined forms, among others a small stem of *Lepidodendron*, showing distinctly the scars and various small branches of Conifers, or Zamiæ, or Lycopodiaceæ. "Those remains," he said, "are in the Red-beds, on an horizon appearing to us when examining the locality as Lower Triassic, or Permian, or Carboniferous. A thin seam of coal was also discovered, adjacent to the beds, and one tiny shell."

Some time later Mr. Lakes sent me a box of specimens from the locality mentioned above, asking me to determine them if possible, to report to him what evidence on the age of the formation could be derived from these vegetable remains, and to send the specimens to the Museum of Comparative Zoölogy at Cambridge.

Though the specimens are very small, covered with mixed minute fragments of leaves, scales, flowers, and seeds of Conifers, leaflets of Ferns, etc., I was able to recognize, in all those which could be determined, the characters of a Permian vegetation, and I reported to Mr. Lakes accordingly.

Being then about to publish the list of the determined species, with some remarks upon them, Prof. Samuel Scudder, to whom the insects had been sent, advised me that, from the characters of the animal remains, his conclusions on the age of the formation did not fully agree with those derived from the plants. As he was going to examine the locality himself, he wrote me that he might perhaps find some more valuable specimens, and that he would communicate them to me when returned home.

These specimens, kindly communicated by Prof. Scudder, were received two weeks ago. Though the vegetable remains preserved upon them are quite as broken, mixed, and indistinct as those of Mr. Lakes, I found a few of them whose determination added some new evidence to that which had been procured already.

The species which I consider as positively determined from all the specimens are the following : —

1. *Collection of the Museum of Comparative Zoölogy.*

CALAMARIÆ. — *Sphenophyllum Schlotheimii* Br., an entire perfectly preserved whorl. No. 1 of the collection.

FERNS. — *Odontopteris obtusiloba* Naum. Nos. 2 and 4.

Neuropteris Loschii Br., or *Cyclopteris cordata* Goepp. No. 6.

Fragment of an *Alethopteris* like *A. lingulata* Goepp. No. 7^a.

Five specimens of fragments of small leaflets of Ferns, not determinable. No. 18.

LYCOPODIACEÆ. — Leaves of *Lepidodendron*. No. 9. The stem of *Lepidodendron* recorded by Mr. Lakes, and rightly described by him in his letter, was not found in the collection.

CONIFERS. — Seeds of *Ullmannia selaginoides* Gein., Leitpfl. No. 8.

Scales or involucres of *Walchia* ! *linearifolia* ? Goepp. No. 10.

Young leaves of *Ullmannia Bronnii* Goepp. No. 11.

Leaves (detached) of *U. frumentaria* Goepp. Very abundant, and mixed with those of *U. Bronnii*. No. 12.

Leaves of *U. selaginoides* Gein. No. 13.

Branches bearing leaves of *Walchia piniformis* St. No. 14. Abundant and variable.

Fragments, mostly ground nearly to powder, of leaves, flowers, and seeds of *Ullmannia Walchia*, etc. Nos. 15 and 16.

Branch of *Ullmannia Bronnii* Goepp. No. 17.

2. *Collection of Prof. Scudder.*

CALAMARIÆ. — *Sphenophyllum emarginatum* Br. No. 9. Good specimen.

Fragment of rachis with a few leaves of *Sphenophyllum* species, Gein., as figured in Nachtr. zur Dyas, I., Pl. I. fig. 22.

FERNS. — *Schizopteris* species. Same as figured in Gein., Ibid., Pl. I. figs. 18, 18^b. No. 6.

Sphenopteris Geinitzii Goepp. No. 7. In many specimens.

Hymenophyllites Leucharti Gein. No. 8.

Cyclopteris rarinervia Goepp. No. 10.

Sphenopteris coriacea ? White & Font. No. 11.

Goniopteris Newberriana ? White & Font. No. 12.

Pecopteris arborescens Brgt., in fruit. No. 13.

Cyatheites Beyrichi Weiss. No. 14.

Callipteris conferta ! var. *obliqua* ? Weiss. No. 15.

Sphenopteris dentata ? White & Font. Nos. 15^a and 16.

Small fragments of Ferns indeterminable. Nos. 17, 18.

LYCOPODIACEÆ. — *Lepidophyllum* species. Sporange and blade. No. 5.

CONIFERS. — Leaves of *Walchia longifolia* Goepp. No. 20.

Leaves of *Abietites* Goepp. Fragments in many specimens. No. 21.

Leaves of *Ullmannia frumentaria* Goepp., and *U. Bronnii*, No. 1, abound.

Branches and leaves of *Walchia piniformis*, No. 3, in plenty of specimens.

CORDAITEÆ. — *Cordaites borassifolius* Ung. Very fine specimen. No. 4.

Fragments of leaves of *Cordaites* species. No 22.

Cardiocarpus orbicularis Goepp. No. 24.

Cardiocarpus species nov., allied to *C. gibberosus* Gein. No. 25.

Carpolithes species, one referable to *C. humidus* Heer, the other, very small but in plenty of specimens, to *C. Geinitzi* Heer, Perm. Pfl. of Funkirchen, Pl. XXII. figs. 5, 6, 7, 8, and 13. These are all mixed with ground fragments of scales, leaves, etc. of *Walchia* and *Ullmannia*. No. 26. Same as No. 16 of the collection of the Museum of Comparative Zoölogy.

On the above species of vegetable remains I add a few remarks in regard to their evidence for the determination of the age of the formation where they have been found.

The genus *Sphenophyllum* ranges from the Silurian to the base of the Permian, as far as known, at least, by the present state of our knowledge in vegetable palæontology. Three species of the genus are recorded by German authors, as from the Permian: *Sphenophyllum Schlotheimii*, *S. emarginatum*, and *S. longifolium*. But all are from the lower strata of the Old Red Sandstone, whose flora is so intimately connected by its characters with that of the Upper Carboniferous that the exact limitation between the formations has not been fixed. It is the same with the Permo-Carboniferous strata of Virginia, wherefrom a number of species of *Sphenophyllum* are described by White and Fontaine. Here we are not yet in the true Permian. A very small and obscure fragment of a *Sphenophyllum* species is described by Geinitz, Nachtr. zur Dyas, I., p. 10, Pl. I. figs. 22, 23. It is as yet the only trace of the genus in the Middle Permian. The specific characters are not discernible, and the author remarks that he has published it only because it is as yet the only species of *Sphenophyllum* found in the Permian of Germany. The presence of two species of this genus in the specimens of Fairplay would be already sufficient authority for referring the formation to the paleozoic time.

In the Ferns, the specimens represent *Neuropteris Loschii*, a species found already in the whole thickness of the Carboniferous, and also in the Permian of Europe. *Pecopteris arborescens*, Upper Carboniferous and Lower Permian. *Callipteris conferta*, one of the more abundant species of the Permian in Europe, and found until now on this continent only in the Permo-Carboniferous beds of Virginia. *Odontopteris obtusiloba, Cyclopteris rarinervis, Odontopteris cordata* which is scarcely distinguishable from *Neuropteris Loschii, Cyatheites Schlotheimii* var. *latifolia, Sphenopteris Geinitzi, Hymenophyllites Leuckarti*, as well as a *Schizopteris*, are all Permian species only. The other named species of Ferns are uncertain on account of the insufficiency of specimens, but they are referable to types of the Permian or Permo-Carboniferous.

In the Conifers, the most abundantly represented in the specimens of Fairplay are the two more distinctly characteristic of the Permian, *Ullmannia frumentaria* and *Walchia piniformis*. There are besides numerous leaves and branches of *Ulmannia Bronnii*, and leaves of *U. selaginoides*, of *Walchia longifolia*, and of *Abietites*, species all representatives of the same formation only.

In the Lycopodiaceæ, Mr. Lakes has found a branch of *Lepidodendron* which I have not seen among the specimens, but two of them have fragments of leaves of this genus, and a *Lepidophyllum* with blade and sporange. It is well known that the Lycopodiaceæ disappear at the base of the Trias, or rather in the Upper Permian. The same can be said of the *Cordaites*, of which *C. borassifolius* is represented upon the largest fragment of shale I have seen from Fairplay.

The age of a flora is indicated, not only by the presence of certain types, but by the absence of others. And in this, the group of vegetable remains in Fairplay is remarkably free of any fragments of plants characterizing the Triassic period. There is no trace of Equisetaceæ or of Cycadeæ. The fragments doubtfully referred to Cycas by Mr. Lakes in his letter are all leaves of *Ullmannia frumentaria* and *U. longifolia*. The Ferns are of a totally different character also. Prof. William Fontaine has prepared a memoir, descriptions, and figures of a large number of species of plants obtained from the so-called Triassic measures of Virginia, which he considers as the equivalent of the Rhetic of Europe. On these plants, Prof. Fontaine writes me that none of them could be referred to the Permian, or to any of the species which I have recorded from the specimens of Fairplay.

Possibly these Permian fossil remains will help to determine the geological distribution of the strata of South Park. In Dr. F. V. Hayden's Annual Report of 1873, Dr. A. C. Peale gives a section of the valley from Platte River to Trout Creek, on a distance of six miles. The section passes about five miles north of Fairplay. Its lower part, or beds No. 18 to 50, represent an open series of 1,250 feet of strata, all hypothetically referred by Dr. Peale to the Carboniferous or Permian, for no fossils of any kind were found to prove it. Above this there is a covered space (beds No. 51 and 52) of 1,300 to 1,500 feet, which is referred to the Red-beds or Triassic. The whole is covered by a thickness of Jurassic strata, overlaid by about 2,000 feet of Cretaceous. From this it appears very probable that the remains of plants found by Rev. Mr. Lakes first, and after him by Prof. Scudder, represent part of the first series of beds No. 18 to 50, all exposed and as yet hypothetically referred by Dr. Peale to the Carboniferous and the Permian. The exact location of the plant-bearing beds in the section of Dr. Peale may probably be easily determined.

October, 1882.

No. 9. — *On the Relations of the Triassic Traps and Sandstones of the Eastern United States.* By WILLIAM MORRIS DAVIS.

1. INTRODUCTORY.
2. LITERATURE.
3. OBSERVATIONS. Nomenclature. — A, Turner's Falls. — B, Mount Tom. — C, West Springfield, Mass. — D, Beckley Station. — E, Meriden. — F, Wallingford. — G, New Haven, Conn. — H, Fort Lee and Englewood. — J, Weehawken. — K, Jersey City. — L, Paterson and Little Falls. — M, Feltville. — N, Martin's Dock. — O. Point Pleasant Station. — P, Lambertville, N. J.
4. BRIEF STATEMENT OF FORMER VIEWS.
5. GENERAL DISCUSSION. Origin of the Triassic Estuaries and Cause of Trap Eruptions; Origin and Deposition of the Strata; Composition of the Trap; Relations of the Trap and Sandstone; Review of Previous Ideas; Test-Characters for Intruded and Overflow Sheets; Examples of these elsewhere; Dikes; Intrusions; Overflows; Amygdaloids; Effect of Trap on Sandstones; Tilting; Theories to account for the Monoclinal Structure; Faults; Folds.
6. SUMMARY.

1. INTRODUCTORY.

SINCE seeing in 1877 the trap conglomerate on the back of Mount Tom, I have doubted the generally accepted explanation of the intrusive origin of the Triassic traps, and inclined to Hitchcock's theory of their origin by overflow contemporaneous with the deposit of the sandstone. During the past summer the desired opportunity came to examine the question further, by personal observation, in Massachusetts, Connecticut, and New Jersey, as detailed below, and with the result of satisfying myself that both views are correct; that some of the trap sheets are of intrusive, and some of overflow origin. The Palisade range along the Hudson may be taken as the type of the first, as has been shown by Russell; Mount Tom in Massachusetts represents the second, as was shown by Hitchcock. Other examples will be found below.

My endeavor has been to discover critical points that give decisive evidence one way or the other as to the origin of the trap sheets, so as to compel instead of merely allowing an explanation; but observations satisfactory or compulsory to one observer are not always so to another, and I cannot, therefore, expect that what has convinced me will surely be equally convincing to those who have thought differently; but to those who agree with my conclusions, as well as to those who differ from them, I would quote the wish of the elder Silliman: "I take the liberty to request, that those who may have it in their power will make precise observations upon the appearances at the junctions, ... accompanied by drawings and specimens when it is convenient; and at least with accurate descriptions. We might thus be in a condition to form a general opinion of the origin of our trap rocks." *

2. LITERATURE.

A number of unimportant references to the Triassic rocks in Annual Reports of State Surveys are omitted in the following list. These can easily be found, if desired, by following Prime's "Catalogue of Official Reports," etc., in the Trans. Amer. Inst. Mining Engineers, VII., 1879, 455. Papers referring only to fossils and date of the deposits are also omitted, as the question of the age of the strata, for which the generally accepted determination is adopted, does not now arise. References to the articles cited are made in the text below simply by page number if the author has but one title in the list; by letter and page number, if several of his papers are given. Pages in parentheses after a title show that only those pages of the paper are devoted to the Triassic formation. Papers that have not been seen are marked with an asterisk.

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3. OBSERVATIONS.

The following observations were made in the summer of 1882. The attempt has been made in recording them to keep inference distinct from observed fact, though the two may come in the same sentence. The observations have been reduced as far as possible to graphic form, for ease of reading as well as for the convenience of those who may care to repeat them. It should be remembered that they are mostly the work of short excursions, made with the object of discovering the position and condition of the rocks only at certain points, and not with any idea of preparing complete geological maps of a district. The plans are generally traced from topographical or geological maps; none of the sections are constructed accurately, but all are kept down near natural proportions. In order to avoid too much assumption in these sections, all lines of contact not directly seen are drawn broken-dotted (—·—·—); the Hanging Hills section is an accidental exception to this rule. The scales of maps and sections are only approximate. The observations are referred to in the text farther on by the letters at their headings.

Nomenclature. — The trap ranges are grouped according to Percival's method: the largest of a system is called the *main range;* lateral ranges on the outcrop side or face of the main range are called *anterior;* on the back or dip side, *posterior.* These lateral ranges are numbered according to their distance from the main range. In the case of overflows, these terms have the unforeseen advantage of serving to denote the relative dates of eruption. *Upper* and *lower contacts* are between the trap and the overlying and underlying sandstones. *Dike* (except in quotations) is restricted to masses of igneous rock clearly of later date than the rocks they intersect, and with a greater extension across the layers of sandstone than parallel to them. *Sheet* is applied to interbedded masses of trap, of intrusive or of overflow origin. *Sandstone* is sometimes used in a general sense, applying to the whole formation, and is then not closely limited to its lithological meaning. *Bearings* are all magnetic. *Page references* to previous writings are made in parentheses after the author's name; the titles are given in the list above.

A. *Turner's Falls, Mass.* (figs. 32, 33, 34). — This manufacturing town is on a corner of land on the left bank of the Connecticut, which here makes a considerable detour from its usual course, and on the way exposes an excellent continuous section of sandstones and trap for more than a mile. This is best examined by beginning on the northwestern bank, one eighth of a mile below the lower suspension bridge (A, fig. 32), where the back of the main trap range is clearly seen. This range has its beginning on the southwest flank of Mount Toby in Sunderland, in a layer of trap making an inconspicuous ridge; Hitchcock has described its upper contact with sandstone in a brook a mile and a half southeast of Sunderland. It then advances northwest, and ascends on the back of Deerfield Mountain, gaining the summit a few miles before the Deerfield River cuts through the ridge to the Connecticut; two railroads pass through this gorge and cut the trap, but do not, so far as I could see in passing, show any contacts. East of Greenfield the Poet's Seat is the culminating point; here the ridge is doubled, with a shallow valley along its top, probably indicating a bed of sandstone or tufa, or a strike fault. It is the upper surface of this main trap sheet that comes to the river's edge below Turner's Falls (A, fig. 32); and going up stream the bright red shaly sandstone is soon met lying upon its vesicular, amygdaloidal surface, quite conformable to its slight irregularities, and showing no signs of local baking at the junction, or of any branching intrusions from the trap below. The sandstone strikes N. 65° E., dips 35° S. E. throughout the section. Following up the bank, we pass obliquely across the strike of the sandstone, and just before coming to the bridge reach the first posterior trap (B). The contact is unfortunately hidden here; it might be found by searching on the face of this posterior ridge farther northeast. The trap is at first dense, but a little beyond the bridge becomes vesicular, and so continues up to the entrance of Fall River. Looking southwest across the river, one may see an outcrop of rocks about in line with the strike of this trap, but they seem to be bedded; no ridge is visible in that direction, and I believe the trap ends about where the river crosses it. Going up stream the trap is seen continuously except in two places where covered by sandstone: the first is in a little hollow on its back (C), about one third of the way to the mouth of Fall River, where the bedding of the sandstone is somewhat uneven, but not more so, I imagined, than would result from the washing in of sand and mud to fill an irregular hollow; this exposure is about twenty feet square; the second is a much larger triangular patch of sandstone (D) at the mouth of Fall River, giving excellent contact specimens, very little weathered, retaining the usual texture, softness and color of the sandstone directly to the trap surface, and holding small scraps of trap clearly separated from the mass below (see fig. 34). A wooden dam gives passage across Fall River near its mouth, and directly opposite (S. E.) there is a small exposure of sandstone overlaid by trap breccia, with contact hidden. Farther up this valley, by climbing up its steep southeast bank opposite a road bridge, a larger exposure (E) is found some eighty feet over the stream. The sandstone is gray and micaceous, and dips a little steeper than usual; its contact with the igneous rocks is hidden, but after a blank of say five feet there is a bank of tufa containing fragments of hard trap. The tufa is deeply weathered, so that I could get no good specimen with fresh surface; it shows parallel lines on its weathered front, which seem to indicate bedding, as they were conformable with the sandstone strata below. The trap fragments here are round or oval, not angular as by the dam; some are as much as two feet in diameter, with a hard, dense surface, but vesicular within; they may be volcanic bombs. Twenty to thirty feet will probably cover the thickness of this tufa bed; next comes the dense trap of the second posterior range, well exposed at its southern end in a rocky point on the river bank; passing around this, we come to the third exposure (F) of overlying sandstone, showing the same features as the first. This trap also is not apparent as a ridge farther southwest, but points to a sandstone island in the river, and may, like the first posterior ridge, end about where the river cuts it. From here up to the falls, one fourth of a mile, beds of shale, sandstone, and conglomerate are well exposed in ascending section, but no more trap appears. The close conformity of the trap and sandstone throughout this series is noticeable.

This section is described and figured by Hitchcock (*d*, 423; *e*, 653, here copied, fig. 7). Numerous specimens of foot-prints have been found in the neighborhood. Emerson's recent article on the Deerfield Dyke and its minerals appeared after the above description was written: it confirms the overflow origin of the trap, but speaks of only two trap ridges, and regards these as originally one, now separated by a fault in the Fall River valley. I do not consider the evidence offered in favor of this view as fully excluding the idea of separate overflows of limited area, as above suggested; although, so far as the origin of the trap is concerned, it is immaterial whether the ridges are regarded as a single sheet faulted or as separate sheets.

B. *Mount Tom, Mass.* (figs. 35, 36, 37). — This section is one of the best I have seen. The following description is reversed from the descending order in which the observations were made. The bench on the western face of the mountain below the talus of trap fragments is dependent on a hard sandstone conglomerate; it forms a ridge by itself from the southern end of Tom over two miles to Rock Valley, where it dies away. The rock quarried at Mount Tom Station, Connecticut River Railroad, seems to be of the same horizon. From this bench the sandstone is generally hidden by trap blocks; but about three quarters of a mile north of the end of Mount Tom, there is a small exposure of sandstone in contact with the great trap cover; others doubtless occur, but on finding this one I searched no farther. The sandstone here, a few feet from the trap, is gray, micaceous, and clearly bedded; but near and at the contact it is dense, as hard as quartzite, bluish, and somewhat like the trap itself in appearance, with only the larger bedding-joints remaining. The two rocks are not welded together here: an open seam separates them, so that no single specimen shows both. The trap is dark, dense, fine-grained, and excessively hard; it lies evenly on the layers below without cutting them; the columnar structure does not show for some ten feet higher. Along the mountain summit the texture of the rock is much coarser, the crystals are occasionally a tenth of an inch in length. Descending the long eastern slope by a wood road, there was no clear evidence of any persistent variation in form, such as occurs by the Poet's Seat in Greenfield, or on the back of the First Mountain, south of Paterson, N. J. The entire mountain seems to be a single heavy trap sheet, several hundred feet thick. When nearly at the bottom of the valley, between the main and the posterior range, an excellent series of exposures was found in a little gully leading down the slope. First there was a glaciated surface of firm trap. Descending a little farther (*ascending* in the geological series), there was found some forty feet of ragged, rough surface, in part trap, and in part clearly a mixture of angular trap fragments with sandstone. The surface of the trap is often vesicular, and in places shows included fragments of a denser kind. The sandstone is reddish, not nearly so hard as that found on the western face of Mount Tom, though harder than some of the soft fragments of trap, which weather out leaving a rough framework of sandstone; at some points the bedding can be seen, but exposures are generally too small and rusty for this. The trap fragments in the sandstone vary from small grains up to pieces one to three inches in diameter; some are dense, some vesicular. This locality is about one fourth of a mile north of a strong gap in the posterior ridge, and is marked by a five-foot boulder of light granite. Crossing the marshy stream, a small outcrop of ordinary normal sandstone is seen on the opposite slope; similar outcrops are found one fourth of a mile farther northeast, higher up on the face of the posterior ridge; and finally, just below its trap, several feet of well metamorphosed sandstone appear, gray in color and quartzitic in texture. The trap here shows nothing peculiar. Crossing over the ridge and descending a quarter of the way to the river, we leave the trap and come to numerous outcrops of conglomeratic sandstone, darker in color than usual, and containing plentiful scraps of trap, many of them vesicular, and in size up to three inches. The first of these outcrops is not more than fifteen or twenty feet over the trap; many others appear at a greater distance, even on the railroad a little below Smith's Ferry Station. It was there that I first saw them in 1877, in company with Professor N. S. Shaler and Mr. J. S. Diller.

The upper contact was not found among these outcrops, but it is excellently shown in Delany's Quarry, on the railroad and river bank, not quite half-way from Smith's Ferry to Holyoke. (From the quarry to Holyoke Station is about an hour's tiresome walk along the hot, sandy track.) Here the rock is freshly worked, and the upper surface of the trap is well shown to be very amygdaloidal, uneven, and knobby, as a lava flow might be, and upon it lies the fine dull dark reddish muddy shale, fitting closely to the trap and filling up its inequalities, so that the sandstone a few feet higher is evenly bedded (see fig. 37). This contact shale is as soft as ordinary shale at a distance from the trap; it is easily scratched to powder with a knife. On some trap faces patches of similar shale appear to be included in the trap, but as they also are not metamorphosed, I consider them to be muddy fillings of cavities near the rough old lava surface, reached by passages not now exposed to view; where their bedding shows, it is about parallel to that of the sandstone above. There was no appearance of branching intrusion into the sandstone, or of breaking across its layers. I looked carefully at a great number of freshly exposed amygdules here and elsewhere, in hopes of finding some of them banded like those at Brighton, Mass. (see Boston Soc. Nat. Hist. Proc., XX., 1880, 426), but was always unsuccessful. Ten or fifteen feet of sandstone over the trap are well shown in the quarry. Several layers contain distinct fragments of trap, rather angular in form, and variable in structure from dense to vesicular. These layers are darker than the normal red sandstone, some being nearly black, presumably on account of the trap sand they contain; some might be mistaken for metamorphosed sandstone, as they have faint bedding, and in a rough way resemble trap; but they grade into normal reddish sandstone below as well as above, and this clearly shows that their color is not due to metamorphic action. There is a strongly slickensided joint at right angles to the dip in this quarry, with some evidence of a fault of several feet throw.

Hitchcock wrote (*e*, 442) that a tufaceous conglomerate "reposes on the greenstone on the east side of Mounts Tom and Holyoke; and consists of a mixture of angular and rounded masses of trap and sandstone, with a cement of the same materials. . . . . I do not doubt but the same rock may be found on the east side of nearly all the greenstone ranges in the Connecticut Valley. Its thickness is but small, and it graduates on one side into greenstone, and on the other into sandstone." This evidently refers to a bed similar to those above described, and points to the same conclusion. He refers to it again in the Ichnology (*h*, 17). Lyell (*a*, 794) visited this region in his company, and concluded "that there were eruptions of trap accompanied by upheaval and partial denudation, during the deposition of the red sandstone." Dana quoted Hitchcock's results in 1863, and added, "But after an examination of the region the author regards it more probable that the appearance of scoria is owing to an escape of steam laterally from between the opened strata during the ejection of the trap of the adjoining mountain." (*b*, 430.) Emerson's observations, made recently (196), confirm Hitchcock's and those of the present writer. In his last edition of the Manual (1880), Dana makes no mention of overflows.

C. *West Springfield, Mass.* (fig. 38). — About two miles west of this station on the Boston and Albany Railroad, the track passes through a short cut in the second posterior trap ridge near its end on the north bank of the Westfield River, and fortunately reveals some twenty feet of sandstone below the trap, as may be seen even from a passing train. The natural outcrops in this neighborhood are very poor, as the ridge is almost smothered in the high sand plain of the Connecticut River. The main ridge and the first posterior are also very poorly shown as far as critical outcrops are concerned, though the trap itself is well opened in the city quarry by the railroad on the west face of the main ridge, where distinct columnar structure is apparent. In the railroad cut, it is noticeable that the hardness of the lower sandstone does not depend entirely on its distance from the trap, but rather on its composition. A sandstone stratum, some twenty-five feet below the contact, is red and very hard; then comes some softer red shales; above these some soft gray shales, and finally, next to the trap, several feet of hard red sandstone. The strata strike N. 25° E.; dip 20°, E. S. E. The two rocks here are very firmly welded together at their junction; the line is slightly irregular, but its average conforms precisely with the bedding. Within a foot of the contact, the sandstone is somewhat vesicular; within an inch, its color changes to light gray, and in texture it becomes a firm dense quartzite. The adjoining trap is dark and dense, and but slightly amygdaloidal. The rest of the cut is all in trap, but the rock is by no means of uniform structure. There is first a mass from twenty-five to thirty feet thick (at right angles to dip), of which the greater part is ordinary dense trap; but its upper six to eight feet become very amygdaloidal and loose-textured, and the upper limiting line, clearly seen on both sides of the cut, dips closely parallel to the sandstone strata; near the bottom of the cut it exhibits some irregularity. Over this, but separated by an open seam, comes a second mass of dense trap, of about the same thickness as the first. This is not so decidedly amygdaloidal as the first in its upper part, and is limited above by a very even six-inch band of coarsely crystalline trap, distinctly visible on both sides of the cut. Ten feet higher, there is another coarsely crystalline band, four inches thick, then say eight feet of massive trap overlaid by drift; no upper sandstone could be found. These even persistent bands dip parallel to the sandstone; they are rather abruptly interpolated in the trap, and the whole is firmly welded together. I do not feel satisfied with any suggestion yet presented in explanation of them; but there can be little doubt that the lower mass with its amygdaloidal cover is a single lava flow, buried under later eruptions. One can hardly imagine a clearer example of the kind. A number of small faults can be seen on the sides of the cut, well marked by a foot or so of brecciated trap; the fault planes are all at right angles to the dip of the sandstone; the largest throw was only a foot, with uplift on the east.

I have been unable to connect the ridges here with the single posterior range by Mount Tom, and cannot say how they are related to one another.

D. *Beckley, Conn.* (fig. 39). — The several curved ridges shown on Percival's map (1, 2, 3, north end of E. III.) in the towns of Berlin and

Wethersfield, give clear explanation of the two causes that have produced the crescentic outlines so characteristic of the trap. The first (1) is shown to be a flat fold, a faint canoe-synclinal outcropping to the north and west, by the close parallelism of the sandstone ledges around its front; their strike changes so as to run parallel to the trap bluff, and they dip towards and under it on three sides. The trap shows a steep face on the convex, and a long gentle slope on the concave side of its crescent. It is undoubtedly a thin overflow sheet; for although no contacts were seen, normal red sandstone was found three feet below the trap, and red shaly sandstone fifteen feet above it, on a cross-road a quarter of a mile southwest of Beckley Station; and the trap is compact at the bottom, and very loose and amygdaloidal on top. Evidently, then, the sandstones and the trap have been here slightly folded together, and erosion has revealed their canoe-form precisely as it has brought out the greater canoes of Medina Sandstone in Pennsylvania. The eastern side of the canoe is not visible except at its northern end, or bow as it may be called, because the fold is canted over on the east. The fold as a whole has a gentle eastward dip.

The second curve (2) is made of trap much like that of the first, and it is very probably the same trap sheet brought to the surface again by a north and south fault with upthrow of forty or fifty feet on the east; its curve does not seem to depend on a fold, but simply on the cross valley of the Mattabesic; for a stream cutting through a monoclinal ridge always produces such a retreat in the outcrop line of its determining hard stratum. The second and third crescents are therefore to be regarded as parts of a single fold, cut into the imitation of a double fold by the stream between them.

It becomes, therefore, an important matter to determine which of the crescentic ridges shown in Percival's and other maps are due to folding of the trap sheets, and which to erosion without folding; E. I. and E. II. are undoubtedly folds; so is the great curve of E. IV. that runs up into Massachusetts. New Jersey shows several others. But the peculiar forms of E. IV. 1, 2, 3, are chiefly, if not entirely, due to erosion, as is shown under the next heading.

Percival gives a close description of the facts about Beckley (358), but makes no statement of their cause.

E. *Meriden, Conn.* (figs. 40 – 43). — Two days' walking about the Hanging Hills and Lamentation Mountain failed to discover any contacts, very probably on account of keeping mostly to the roads so as to cover more ground, for the work here was chiefly stratigraphical.

The main result found was that the Hanging Hills and the neighboring trap masses marked on Percival's Map, E. IV. 1, 2, 3, 4, 5, and probably 6, and others farther north, are all parts of a single trap sheet of overflow origin, broadly and faintly folded into a very flat synclinal, perhaps a little faulted, and deeply cut by erosion around the margin. It is pretty surely an overflow, because it has small influence on the sandstone when the two are seen near together, and its upper part is very amygdaloidal; and because it makes part of the Mount Tom range, whose overflow origin is well established. The former union of the now separate hills is made sufficiently sure by the nearly uniform height of the hills on the opposite sides of a gap (see section, fig. 41); by the uniform slope in a single plane of the separated parts of the sheet (fig. 40); by the conformity of this slope to the dip of the adjoining sandstone, wherever seen; and by the regular position of the first anterior ridge on the slope below the great bluffs. This is not apparent from Percival's description or map; on the latter, his outlines indicate only the ridges or elevations, not the areas of trap. Professor Dana's reduced copy of this part of the map (*c*, 418) unites the hills as here drawn, but he regards their trap as an intruded sheet (*d*, 41). West Peak (E. IV. 3), the highest of the Hanging Hills, owes its height over 2 and 4 to being at the southwestern end of the flat synclinal; to the same structure is due the change in the direction of the bluffs at this high point from a north and south to an east and west line. E. IV. 5 is higher than 4 chiefly because it is farther from the axis of the synclinal; it is noteworthy that the oblique gaps between 3 and 4, 4 and 5, etc., are about parallel to this synclinal axis, and may very probably indicate the position of subordinate bends or breaks.

I believe it probable and provable that Lamentation Mountain (E. III. 5) is a reappearance by faulting of the Hanging Hills overflow sheet, and it may extend even through E. III, II, and I, as is explained below under faults and folds.

F. *Wallingford, Conn.* (fig. 45). — The sandstone in this neighborhood is loose and coarse, with well-marked cross-bedding; it is cut by many dikes, as was first stated by Chapin in 1835, but there are also several sheets nearly conformable to the bedding. The dikes are well seen on the road to Cheshire, half a mile or more southwest of the Wallingford Station (New Haven and Hartford Railroad), where they break through the sandstone very irregularly: they are from five to twenty feet thick, but do not affect the adjoining sandstone for more than a few inches. Fig. 45 shows the ragged edge of one of them.

Besides the dikes, there are sheets of trap cutting the sandstone at a small angle, or perhaps in places conformable to the bedding. One of these begins close to the corner of the Middle Turnpike and the Cheshire road, and can be easily followed several hundred feet obliquely up the slope to the northwest; it makes a little bench on the hillside, rendered clearer by some quarrying work at several points; it is about fifteen feet thick, dense throughout, and its columns are closely at right angles to its bounding surfaces; the sandstone is baked for a few inches below it, and the only sandstone found on its back was hardened. Another similar bench is seen a little higher; and a third makes a well-formed *mesa* near by, locally known as Mount Tom. All of these are probably intrusions; but they have not the regular vertical position shown in Chapin's general section (see fig. 8). The trap here is more irregularly intruded than at any other place I have visited.

G. *New Haven, Conn.* — There is a good exposure of sandstone on the southwestern face of West Rock under the trap. The strata here are of coarse granitic sand, and red and purple shales; sometimes firm, but with several purple shaly beds; they do not show so much metamorphism as the rocks beneath the Palisades, but nevertheless appear to be distinctly changed from their original condition for several feet from the trap, thus gaining a compact crystalline texture in certain layers. The trap is fine at the base, where it is conformable to the sandstone, and very compact through the whole mass: no amygdaloid was seen at any point on the face or back.

The eastern slope near the southern end of the Rock is covered by shaly sandstone for a considerable distance toward the top; it is often exposed in little gullies, and shows a variety of colors from gray to purple and bright brick-red. But for several hundred feet beyond the uppermost exposure, no rock is seen till the firm trap appears; at least such is the case on the path leading up to the "Judges' Cave,"* and along several gullies farther south. Undoubtedly a junction may be found by searching farther to the north. In the covered space, several fragments were found resembling baked shale; they are probably from nearer the junction.

Pine and Mill Rocks are simply large dikes of compact trap, about vertical, cutting across nearly horizontal granitic sandstones; a marked consolidation has been produced by their heat for ten or twelve feet at least from their sides. Their width and direction are variable: the former is certainly as much as two hundred feet at some points; and their general trend is east. A rough but distinct columnar structure is seen at right angles to the sides. Their junction with the sandstone is somewhat irregular; but this is natural, as the latter has no well-marked joint planes.

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* A rude shelter under some boulders, where "Cromwell's Judges" were concealed for a time.

East Rock shows two patches of lower sandstone on its southwestern face; they are very similar to that described under West Rock, except that about eight feet below the conformable junction, a spotted appearance has been produced in a layer of purplish granitic sandstone. The trap is also like that of West Rock. Ascending by the road on the southern side of the hill, and when the eastern slope is reached turning across a field into the wood, a very strongly baked granitic sandstone is found within a few feet of the fine compact trap: the sandstone is very dense and much more crystalline than any found elsewhere in the Connecticut valley, but it rapidly loses this character, and becomes soft and fragile farther down the hill, like that found on the back of West Rock.

A number of dikes (fig. 44) may be found by crossing the river from New Haven by Tomlinson Bridge, and continuing half a mile along Forbes Avenue toward East Haven. These were long ago described by Hitchcock (*b*, 56), but his figure (here copied, fig. 2) makes them much too regular; they vary in strike and dip as well as in thickness, and their sides are uneven. They are not at all amygdaloidal; their baking extends one or two feet into the adjoining granitoid sandstone. The second cut on the Shore Line Railroad east of Fair Haven shows a similar dike; but the third cut is in a coarse granitic sandstone that makes a strong ridge by itself, being hard enough to stand up between the softer shaly sandstones on either side, though not visibly aided by any igneous rock. The ridge west of Saltonstall's Lake (Percival's E. I.) is cut at a low gap by the same railroad, and shaly sandstones are exposed, conformably covered by trap, and baked to white quartzite immediately at the junction, as at West Springfield. The line of contact is broken at one point by a very small fault, displacing the shales and trap equally, and evidently of later date than the eruption. The trap is brecciated at certain points, and is generally uneven in its jointing, and its upper surface along the lake shore is very amygdaloidal. No overlying sandstone could be found.

There is fairly good evidence that the natural gap, cut deeper by the railroad, results from a transverse fault of ten or twenty feet, with the throw eastward on the southern side.

Reference to Percival's description of these ridges is given farther on. Professor Dana gives a brief mention of the traps of this district (*d*, 46; most of this article applies to the quaternary features of New Haven). E. S. Dana and Hawes describe the composition of the trap here and elsewhere, and note an increase in the hydration and alteration of the eastern traps over the western. (See below, under Composition of Trap.) All of the trap is regarded as intrusive by these authors.

From the descriptions given above, and a comparison of this region with others, I am led to believe that the Saltonstall Ridge is an overflow: its small metamorphic effect at the base, its decided amygdaloidal texture on the back or upper surface, its irregular and brecciated structure, and its alteration and hydration, all agree with the characters of overflow sheets rather than with those of well proven intrusions, such as East Rock and the Palisades.

Palisade Range. — H. *Fort Lee and Englewood, N. J.* — Sandstone shows at the water's edge above and below the wharf at Fort Lee. About eighty feet up the hill, under the Bluff Point House, a path cutting shows baked shales seven feet from the trap.* A two-mile walk northward from here leads one obliquely over the range toward Englewood, showing many well-glaciated knobs of coarse, dense trap on the way; the glacial striæ advance obliquely up the back of the range, bearing S. 20° E. A small stream known as Mill Brook, shown close to Floraville, a mile south of Englewood on the Triassic Map of New Jersey (Cook, *a*), gives a good exposure of the upper contact of sandstone on trap.†

The trap is of rather coarse texture when first shown in the stream; it is evenly divided by parallel joints, one to three feet apart, dipping 12° W. N. W., just as the sandstone dips farther on; the columnar structure is subordinate to this appearance of bedding. Following down the stream-bed, the texture soon becomes finer, but is nowhere vesicular, and in a short distance highly metamorphosed sandstones and shales are reached. Their bedding is very even, and not perceptibly disturbed near the trap; their color varies from nearly black to gray or greenish; in texture they are jaspery or distinctly crystalline. The junction was found with difficulty, and only after passing over it many times, up and down stream. It was at last discovered in a block, slightly moved from its original position by frosting and stream-work, but still preserving its joint faces parallel to those in the ledges near by. The ledge from which this block had been loosened was covered; but as trap in place was found two feet below it, and baked sandstone in place three feet above it, I have no doubt that it showed the true place of junction. Its weathered face showed no change of color, and very little change in texture, and specimens showing the actual welded contact were found only after much hammering. They closely resemble those found at the Weehawken tunnel at the under contact; in both cases the igneous rock is bluish black, dense, and fine, and for a quarter of an inch from the contact is chilled to a dark gray; and the aqueous rock is gray or dark, and the more distinctly crystalline of the two. The thickness of the Palisade Range trap between these contacts is, according to a true scale section by Cook (*b*, 200), about seven hundred feet. Some twenty feet of metamorphosed beds are seen farther down the brook; then exposures are rare. A hard reddish-white sandstone was found farther south lying say one hundred and fifty feet over the trap. No posterior ranges of trap are known in this district, unless the Snake Hills back of Hoboken are so called.

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* Contacts could certainly be found by further searching. The bluffs at Shady Side Landing, a few miles down the river, and under Englewood Hotel, two miles up stream, seemed worth visiting, as seen from a passing boat. Mather (282) gives examples of contacts farther north; some of his figures are here copied (figs. 11–14).

† Cook mentions sandstones overlying the trap at Englewood (*b*, 178, 208). I was directed to Mill Brook, as a stream likely to show the desired contact, by Mr. J. H. Serviss, of Englewood.

This excursion can easily be made in an afternoon from New York; going up the Hudson to Fort Lee by boat from Canal Street, and returning from Walton Station, Northern Railroad of New Jersey, to the Erie terminus. It is of value, as upper contacts are rare.

J. *Weehawken, N. J.* (fig. 46). — The several exposures of the sandstones below the trap in this district have been fully described by Russell (*d*); some of his figures are here copied (figs. 30, 31), and a more detailed view of the junction at the point of rocks below the Duel Ground* is added (fig. 46). H. Credner examined the Palisade trap in 1865, and pronounced it intrusive; he regarded the Snake Hills as a branch from the main "emporbrechende Dioritmasse" (393).

It is very probable that the advance of the Weehawken cliffs to the river bank at this point is due in part to the resistance to erosion offered by the chimney or dike of trap, which here descends close to the water's edge, while elsewhere the trap generally rests on a sandstone base, thirty to one hundred feet above the river; but it is also quite possible that a fault, similar to that seen at Garret Rock, Paterson (L), has aided the advance. The intersection of the sandy and shaly layers by the dense trap, and their metamorphism, are excellently shown. The branch dike cannot be traced quite to the greater mass, but they undoubtedly join below the talus; the branch is about four feet thick, generally lying evenly between the layers, but at one point crossing them in an irregular, ragged passage; it is clearly traced two hundred feet horizontally; and where it is lost to sight the main trap mass of the high cliffs above has risen nearly half this distance over it. All the bedded rocks here are thoroughly baked, and near the junctions are more or less clearly crystallized; their color varies from light gray to black, but there are no red beds; the beds above the branch dike are affected quite as stongly as those below it.

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* The Hamilton-Burr duel ground of 1804.

Half a mile farther north, where the tunnel of the West Shore road (New York, Lake Ontario, and Western Railroad) opens on Day's Point, another contact was found. Here the fine dense trap lay evenly on the baked and crystallized layers below it, of which some eight feet were shown; their color was dark or black, not red. This contact will probably be covered by later work. Day's Point, a low triangular projection into the Hudson, where the wharves of the West Shore Railroad are in process of construction, now shows a small ledge of sandstone, rapidly being cut away in the work of grading. It is separated from the trap by eighty or one hundred feet of sandstone, measured at right angles to the dip of 12°. The upper layers of the ledge are firm, fine-grained, and red; the lower are looser, clear white, with some coarser grains of transparent quartz. Similar white sandstone occurs under the cliffs a third of a mile southwest of the Duel Ground.

K. *Jersey City, N. J.* — The recent work of straightening the old cut on the Pennsylvania Railroad gives an excellent section with many fresh exposures through this lower part of the Palisade Range. The trap is generally coarse; in some small patches there were crystals of pyroxene half to three quarters of an inch in length. It was nowhere found to be the least vesicular. Broad joint faces are very common, and faulting has taken place on some of them. Near the eastern end of the cut there is a vein or dike, six inches wide, vertical, trending about north and south, in the trap. It is light gray in color and is composed of a fine granitoid mixture. Its texture is uniform throughout, and the trap shows no change of structure on approaching it. I have found no other example of the kind.

Both Cook (*b*, 216) and Russell (*d*, 43) give evidence to show the existence of a soft bed, probably of sandstone, between the eastern and western part of the trap. Its place in the cut is marked by an open hollow in which no rock is now to be seen, and it is not fully proven not to be a fault like that at Garret Rock, Paterson. There is a longitudinal valley on top of the Palisade Range at Fort Lee, but coarse trap is seen so plentifully on its two slopes that there is little room for sandstone at the bottom; and its cause is very probably a fault. Cook also notes that the trap of the Palisades is remarkably uniform and very hard (*b*, 178).

L. *Paterson and Little Falls, N. J.* (figs. 47, 48). — First and Second Mountains * are here cut through by the Passaic. The flat country back of the broad gap and the considerable quantity of drift in the neighborhood indicate that the present course of the river is not its course during preglacial times of greater land elevation. We cannot, therefore, now see the old valley bottoms, so that here, as on most of the Palisade Range, the back of the trap is stripped of its sandstone cover below the present general surface of the valley drift, and upper contacts cannot be found. In spite of the deep river gorges, and the large areas of trap exposure, I was unable, in searching a day and a half in this district, to find any sandstone lying on the trap; but lower contacts are seen at several points. The best of these is in the gorge below the Passaic Falls at Paterson: on the left bank the exposure is in a high bluff, not easily reached; on the right the trap is quarried for paving-blocks, and a fresh contact constantly shown and easily accessible (fig. 48).

There are red strata of firm sandstone and thin-bedded shale cut below the trap, and up to a few feet of the junction they show no marks of alteration; both can be matched closely at many points distant from any igneous rock. Within a foot of the contact the sandstone becomes firmer than usual, and shows rusty cavities, presumably a metamorphic effect, as they are most numerous by the trap. The upper half-inch of sandstone is darker than the rest but still reddish. The line of junction is easily found and traced; it is parallel to the sandstone layers, and nowhere cuts across them; the slight waving irregularity that it shows does not demand intrusion for its explanation. Specimens are easily broken out showing the two rocks welded together. The mass of the trap in the gorge is dark, fine, and even in texture; farther back from the sandstone it becomes coarser, but no samples were found so coarse as those from the Jersey City cut or from Goat Hill on the Delaware. Close to the junction, amygdaloidal cavities are very plenty; but most of them are within a foot or even half a foot of it, and here the trap is very fine-grained. The lower ten or fifteen feet of trap is of very heavy columns, two to four feet on a side, irregular or roughly rectangular; divided near the middle by rather continuous joints parallel to the sandstone bedding, sometimes breaking the rock into slabs two to ten inches thick. No change of texture is seen at these joints, and some of the columns are continued above and below. The heavy columns suddenly change upwards to smaller ones, six inches to a foot on a side, but there is no corresponding change in the texture of the rock, nor is there any appearance of a seam between the two parts; it is simply a change of jointing, for which I can suggest no satisfactory cause. The smaller columns are not all parallel, but incline in various directions; some variation is shown in the figure where they overhang the lower columns. Where thus irregular in position, they are at right angles to the present surface of the ground (noted also by Cook, *b*, 202, 203). The same change of structure is shown a third of a mile south, by Barber's Mills; again a little farther where the Delaware, Lackawanna, and Western Railroad cuts a bench for its passage around the end of First Mountain, here known as Garret Rock; and finally in the first and third of three quarries opened on the eastern face of the mountain, over the railroad station. Contacts of trap and sandstone show in all but the first of these, but not so clearly as at the Falls; the sandstone shows no effect of heat except the slight one above described. Of these latter localities the most important is that on the railroad (fig. 47), showing two strike faults of small throw. The eastern and greater of the two is covered by a ravine and its rubbish, but is proved by the repetition of shaly sandstone, heavy columns, and smaller columns on either side; from junction to junction measured along the track is one hundred and sixty paces, say four hundred and fifty feet; the junction line dips with the bedding 10°; this gives seventy or eighty feet for the displacement, with downthrow on the east. The second fault, a little farther west in the same cut, is shown to be about eight feet by the displacement of the upper surface of the heavy columns with downthrow to west; the fault is on an open joint, parallel to the columns, and striking with the ridge.

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* Called the Watchung Mountains in Cook's later Reports.

The mountain is most easily ascended by its northwest flank; from any of its higher knobs* a well-marked longitudinal valley is seen separating the eastern from the western summits; it extends several miles with varying distinctness, and is very marked at the Notch, where the

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* Most of these knobs are well rounded by glacial action, and some still retain striæ pointing directly up hill. Excellent scratches on the trap at Little Falls point up into Vernon Valley between the two mountains.

Greenwood Lake Railroad crosses the mountain. As the valley is in line with the larger fault, they probably stand in the relation of effect and cause; the throw has very probably increased where the valley is well formed.

Sandstone was not found in the valley as far south as the Notch, although the place is favorable for its preservation. If continued northward, the fault would pass east of the trap front at the Falls, and its effect, if existing there in the sandstone, would be less noticeable.

On the western foot of First Mountain two small exposures just west of the Morris Canal and south of the High Bridge showed amygdaloidal trap, and one of them presented clear marks of variation in structure bounded by curved surfaces, such as are found farther south at Feltville. There was also seen at this point a surface much like that of flowing lava or slag.

Sandstone is not seen in the flat valley until the village of Little Falls is reached, a short mile west of the First Mountain trap, where it is shown in normal condition in a quarry by the canal and river, about two hundred yards east of the Second Mountain trap. The right bank of the Passaic here approached gives no chance of finding a junction; but on the other side, a little farther down than opposite the quarry, there is a small opening in which fine trap and red sandstone both show, though the contact is hidden by several feet of rubbish. The sandstone has no marks of baking. Following up stream, the trap varies greatly in texture; an irregular very amygdaloidal mass grades into firm trap on one side, and into a much decomposed loose rock on the other; I have considered the latter an ash or tuff. The dense trap is often distinctly columnar, and above the canal bridge it is well divided by nearly horizontal open joints into sheets of varying thickness. In the midst of this there is a very uneven mass of amygdaloidal trap that seems to contain fragments. Farther west there is a broad area of flat alluvial meadow-land.

The trap of this region is described by Rogers (*c*, 146) and Cook (*b*, 179).

M. *Feltville, N. J.* (figs. 49, 50). — Mr. I. C. Russell (*a*) describes an upper contact in a little ravine on the back of First Mountain near this deserted village; but I failed to discover any outcrops corresponding closely to his description. My time there was short, and allowed only the examination of a ravine about an eighth of a mile east-northeast of the village; the stream from it enters the brook in Washington Valley at the lower part of an old broken dam. Going about one hundred yards from the mouth, so as to descend (geologically) below the trap surface, the rock appears firm and hard in the stream bed: shaly sandstone often outcrops on the banks of the ravine, but at no point within five feet of the trap, and generally ten or fifteen feet from it. Returning down stream, the trap becomes amygdaloidal, and shows rounded bosses or knobs similar to those described by Russell; but as seen here they are not directly at the upper surface of the trap. Nearly at the entrance of the ravine, a bank of much-weathered vesicular and fragmental trap suggests a trap breccia, but the surface is too much rusted for determination. The most important exposure here was found in the side of a short adit made some years ago on a small vein in the trap; it is known in the district as the "Copper Mine." It shows (fig. 49) a number of oval masses of trap, up to two feet or more in diameter, contained in a peculiar red and black matrix. The trap masses vary in their texture and color with the distance from their surface; the outer part is black and dense, then amygdaloidal for a few inches with concentric bands of color, and rather dense near the centre. The matrix (fig. 50 a, b) has all the appearance of being a disorderly mixture of small, angular scraps of trap, up to an inch long, held in a soft reddish shaly mass, that shows no signs whatever of metamorphism. Its contrast with the over-lying sandstones at Englewood is very marked, and it is difficult to understand how this could have been formed except on the surface of a pre-existent sheet of lava.

Russell says (*a*, 280), "The section at Feltville furnishes indisputable evidence that the igneous rocks composing the first Newark Mountain were intruded in a molten state between the layers of the stratified rocks subsequent to their consolidation." He describes (*b*) another upper surface of the trap on the back of the same mountain farther south, back of Plainfield, where there is "an amygdaloidal trap passing into a metamorphosed shale," so that it is frequently difficult to detect the difference between the two rocks. I was unable to visit this point.

Feltville can be reached by a pleasant walk of four miles from Fanwood Station, Central Railroad of New Jersey; the Triassic Map of New Jersey, 1867, gives the roads very clearly. It is to be hoped that further observations will soon be made to give evidence for one or the other of the above discordant conclusions. At Fanwood Station, the railroad cuts the unstratified terminal moraine of the quaternary ice sheet (New Jersey Geol. Survey, Annual Reports, 1877, [illegible]; 1878, 16); and good specimens of foreign angular and scratched stones, large and small, are easily found.

N. *Martin's Dock, N. J.* (fig. 51). — Two beds of trap appear in the shales a little above Martin's Dock on the north (left) bank of the Raritan River about two miles below New Brunswick; they are therefore about three miles posterior to Palisades — Rocky Hill trap range, which if continuous is here buried under the cretaceous formation. The lower bed is about fifteen feet, the upper two feet thick, and they are separated by some ten inches of slate; the two are closely parallel to each other and to the strata of shale and sandstone below and above, and all dip ten to twelve degrees westerly; there is no appearance whatever of the traps cutting across the shaly layers that enclose them. The section may be described as follows, beginning at the bottom.

Soft, fragile shales, generally red in color, appear along the shore for several hundred feet down stream: occasionally they vary to a fine, sandy layer, six to twelve inches thick, with rather irregular layers, as if disturbed, although the shale below and above is very evenly bedded. Approaching the trap, three to five feet below it, the shale is grayish, but still soft and fissile; for six or eight inches below the trap, the shale becomes slaty, dark, tending to bluish black, and hard; but in places two or three inches under the junction occur loose, soft, weathered patches quite unlike the firm, dark shale enclosing them. The trap and shale are not welded together; all the junctions are separated by open joints, so that no specimen showing the two rocks together could be obtained. The lower heavy trap layer is firm, dense, dark throughout with finer texture at both junctions, and no appearance of vesicular structure; it breaks into rough columnar blocks, and where these are weathered on the shore, they often have the ragged look of a breccia, but no such structure could be found in the rock in place. The intermediate stratum is a hard black ringing slate: in places it shows a slight breaking and disarrangement of its layers, not by cross-faulting or any general disturbance, but more as if kneaded together. The upper trap layer is dark and dense, like the lower. Above it the rock is very rusty from weathering, and shows an open, loose texture for some six inches; the rusty color continues for several feet, and about ten feet from the trap there are normal soft red shales again.

These trap-sheets must be intrusive, although they show less baking than similar sheets on the Delaware. Cook says (*b*, 202), speaking of the bedded appearance of the trap here and elsewhere, "So strongly marked are these divisional planes, and so closely do they resemble marks of stratification and even lamination, that good observers are frequently unable to tell which is trap and which is only discolored shale." He includes this with the general occurrences of intrusive trap.

O. *Point Pleasant Station, Belvidere Railroad, N. J.* (fig. 52). — The main mass of trap here seems to be a small example of what is shown on a larger scale farther down the Delaware about Lambertville, but the smaller sheets resemble most the little outcrops at Martin's Dock, and are finely shown.

The first outcrops on the railroad are about five hundred feet below the station, where a dark, fine grained trap shows in the bank; it is faintly columnar, but clearly bed-jointed, so that the slabs dip 12° N. 20° W.; the sandstone wherever seen is closely of the same position. There are no amygdules, but on some weathered surfaces the trap is pitted in lines parallel to the bed-joints, showing points of chemical weakness probably determined early in its history. The rock rapidly becomes coarse-grained and light-colored on going northward, and in this form rises to the hill-top; on the slope where seen, it is not columnar, but breaks out in large masses and slabs; it becomes somewhat finer again, but I failed to find its northern limit, which occurs in a ravine. North a little farther and opposite the station is a bed of fine-grained dark trap, again showing distinct bed-joints and little cavities weathered in lines parallel to its lower surface; there is no apparent change of structure to cause them. This trap rests on a fine, brittle black slate; the junction of the two rocks is seen with few interruptions for a hundred feet, and is precisely conformable to the bedding. The upper surface of the trap was not seen; but judging by the form of the bank, the bed is not more than twenty feet thick.

A little above the station there is a cliff, thirty to fifty feet high, of fine black trap; its face is marked by joints a little steeper than a normal to the dip, and dividing the rock into sharp-edged columns (▱); there are other joints parallel to the bedding of the adjacent sandstone; and two four-inch bands of the same dip were traced some forty feet along the face, distinguished from the rest by a peculiar roughness of weathered surface dependent upon short cracks occupied by calcite. This may be called a kind of vesicular structure, but not at all like the ordinary trap amygdaloid. No contacts of this trap with slates were seen, but the slate where found above and below was fine, black, and brittle, and dipped 12° parallel to the bed-joints in the trap.

An eighth of a mile above the station, a dry stream bed gives a good series of exposures to a height of more than two hundred feet over the river. Much the greater part is on fine black shale or slate, or brownish shale of somewhat coarser texture; near the several trap sheets, it is always black and brittle. Mud-cracks were noticed on many loose slabs, and occasionally in place here and farther up the river. Four beds of fine black trap occur in this little ravine: the first two form a single shelf over which a fine thread of water falls (fig. 52), the lower bed being four feet thick, the upper twelve, with four to six inches of shaly slate between them. This parting of slate is seen between the two beds of trap, extending with uniform dip for seventy feet. The slate and trap are very much alike on fresh surfaces, but the slate has a bluish tinge, and shows some signs of breaking on its bedding; the trap is blacker, and its fracture is more conchoidal. Both are jointed into sharp-edged columns, but these are most distinct in the trap. Farther from the trap, the shaly structure is more apparent, and bands of lighter and darker color are sometimes found. The other two trap sheets make two small benches farther up the ravine, and show about the same characters as those just given, but their junctions with the slate could not be determined, so nearly alike were the textures of the two rocks near their contact, and so closely did joints in the trap imitate beds in the slate. Weathered fragments of trap often showed a pitted or scoriaceous surface, though no cause could be seen for this in the structure.

Returning to the railroad, and going north again, the same trap sheets are passed as they descend to cross the river. A quarter of a mile above the station, dark red sandstone appears in the bank, and continues without further interruption; it is fine and hard, though not at all quartzitic; generally thick-bedded, but sometimes shaly and mud-cracked; fine green dots of epidote (?) are found in it. It is very evident that the brittle black slate that adjoins the trap was never like this sandstone.

Rogers (*c*, 156) and Cook (*b*, 192) both refer briefly to this locality. The trap here is shown on the Triassic Map of 1867, but not on the Economic Map of 1881 (Cook, *a* and *d*).

P. *Lambertville, N. J.* — The section along the Delaware by Lambertville is spoken of by H. D. Rogers (*c*, 153; *g*, 685) as affording good examples of the metamorphic effect of the trap on the sandstone on both sides of the igneous mass. Cook shows the same region in a generalized section (*a*, sec. 1, here copied, fig. 26), with the traps lying between the sandstones after the manner of sheets elsewhere. The region is one of difficult study, for, in spite of the deep valley cut by the Delaware, outcrops are not continuous enough to show junctions;

it seems hopeless to look for them here, and I was unable to get good evidence as to the position of the trap. It is surely intrusive, as no amygdaloid is present, and the shales are baked on both sides of the trap ridges; but whether interbedded or in dike form, is rather an open question. Against the sheet form may be noted the small difference in slope of the two sides of Sourland Mountain, and consequently the absence of a well-marked face and back so characteristic of the sheets elsewhere; and the fact that the baked and blackened shale ascends to about the same height on either slope (Cook, *b*, 191). Farther southeast, the several elevations known as Rocky Hill, Pennington Mountain, and Bald Pate are on the other hand probably sheets, as their southern face is steeper than the northern: as suggested by Russell, these are presumably the reappearance of the Palisade curve, which is covered by the cretaceous strata in its middle; its length from Haverstraw on the Hudson to Bald Pate on the Delaware would then be over eighty miles.

4. BRIEF STATEMENT OF FORMER VIEWS.

The following paragraphs show in brief the opinions of various writers on this subject, the districts of their observations, and the dates of their publications.

It was thought that the trap was intrusive by Silliman (Conn., 1810, 1830), Hitchcock (Mass., Conn., 1818), Chapin (Conn., 1835), Gesner (Nova Scotia, 1846), Lyell (Va., 1847), Emmons (N. Y., 1846, N. C., 1858), Cook (N. J., 1868), E. S. Dana and Hawes (Conn., 1874), Kerr (N. C., 1875), Prime (Pa., 1875), and Frazer (Pa., 1876). These authors make no special reference to the effect of the eruptions on the position of the sandstone strata in their writings of the above dates. It was held that the intrusion of the trap tilted the sandstones by A. Smith (Conn., 1832), Percival (Conn., 1842), Emmons (1854), and in part by Silliman Jr. (Conn., 1842) and Hitchcock (Mass., 1844).

The following considered the trap intrusive, but held that the dip of the sandstone was due to some other disturbing force: Jackson and Alger (Nova Scotia, 1833), H. D. Rogers, (N. J., 1836), Hitchcock in part (Mass., 1844), Credner (N. J., 1865), J. D. Dana (Conn., 1863–1880), Heinrich (Va., 1878), and Russell (N. J., 1875–1880).

The overflow origin of the trap was faintly suggested by Gibson (Pa., 1820) and Cooper (N. J., 1822); it was shown to be probable by Hitchcock in 1833, and proved later (Mass., 1841–1858); Dawson came to the same conclusion (Nova Scotia, 1848–1868); it was adopted by Lyell in part (Mass., 1842), and fully by Leconte (1878) and Walling (Mass., 1878). These authors agreed with those of the preceding group in believing that the tilting of the sandstones was the effect of some external force.

The trap was considered passively intrusive, and the dip of the sandstone was looked on as the result of original oblique deposition, by H. D. Rogers (Pa., N. J., 1839), W. B. Rogers (Va., 1840), Mather (N. Y., 1843), Silliman Jr. (Conn., 1844), and Whelpley (Conn., 1845).

The former anticlinal connection of the two sandstone strips in North Carolina was suggested by Kerr in 1874, and extended by Bradley in 1876 to the Connecticut and New Jersey areas. Russell independently made the same suggestion for the latter in 1878.

The trap has been considered a metamorphosed sedimentary deposit by Wurtz and Martin (N. J., N. Y., 1870).

Plate I. may be taken as a pictorial supplement, in illustration of the preceding abstracts. It embraces nearly all the sections that have been drawn showing the Triassic traps within their sandstones. These drawings are not fac-similes, but in the small changes that have been made I think no injustice has been done.

1. Hitchcock (*a*). Across the Connecticut Valley in Northern Massachusetts. The vertical position of the greenstone intersecting the strata of Deerfield Mountain was corrected in his next article (*b*), but in the mean time it had served Cooper as an argument for the igneous origin of floetz-trap.
2. Hitchcock (*b*). East Haven (Conn.) dikes; their sides are too regular and parallel. See our figure 44.
3. Eaton (*c*). Across the Connecticut Valley in Northern Massachusetts; excessively wrong.
4. Smith. Across the Connecticut Valley; sandstone tilted by the trap, which rose through chasms and overflowed at the surface.
5. Jackson and Alger (*b*). Southeastern side of Bay of Fundy.
6. Hitchcock (*c*, 221). Across the Connecticut Valley in Northern Massachusetts.
7. Id. (*c*, 423). Turner's Falls on the Connecticut in Northern Massachusetts. The increased thickness of the main trap sheet at the surface is wrong.
8. Chapin (105). Across a number of ridges at Wallingford in Southern Connecticut. The author failed to observe any interbedded sheets.

9, 10. Chapin (109, 111). Details in the same region.

11, 12. Mather (Pl. V., figs. 5 and 4). Dikes in the sandstone under the Palisade trap, two miles south of Haverstraw, and near Verdrietje Hook.

13, 14. Mather (Pl. XLV., figs. 3 and 2). Sections across Southern New York and Northern New Jersey.

15. H. D. Rogers (*c*). Across the Newark Mountains, Central New Jersey. The interbedded position of the trap is not shown.

16. Emmons (*b*, 200; *c*, 107). Palisade section at Slaughter's Landing, showing intrusions between the beds below the main mass of trap.

17. Lyell (*c*, 271). Dike in the Richmond Coal Field.

18. Dawson (*a*, Pl. V.). North shore of Mines Basin, opposite Two Islands, Nova Scotia. Part of this section gives the appearance of a post-Triassic overflow, but it is all described as contemporaneous.

19. Lesley (*a*, 133). Hypothetical section illustrating the use of "overflow" by Rogers as well as by the author.

20. Hitchcock (*g*, Pl. III.) Mount Tom, Mass., with incorrect increase in thickness of the trap sheet as in fig. 7.

21, 22. H. D. Rogers (*g*, II. 912, 691). Dikes at New Hope and Gettysburg, Pa., producing metamorphism and cleavage.

23. Id. (*g*, Geol. Map Pa., sec. 8). General section near Gettysburg, Pa., showing post-Triassic eruptions.

24. Emmons (*d*, sec. 1). Dike in North Carolina.

25. Cook (*b*, 200). True scale section of the Palisades. The author says this "fails to impress the mind" as one of the exaggerated sections does; but it certainly has the advantage of giving a true impression.

26. Cook (*a*, sec. 1). East bank of Delaware by Lambertville, N. J. There is some doubt as to whether these trap masses are sheets as here shown.

27. Frazer (*a*, 298, sec. 11 a). Dikes near Gettysburg, Pa. It is not definitely stated in the context whether faults exist as shown in this section.

28. Leconte (440, 441). Hypothetical section of the Connecticut Valley. If drawn on true scale the amount of erosion would be still more enormous.

29. Russell (*c*, 230). Hypothetical section of the New Jersey and Connecticut Triassic belts, showing their supposed anticlinal relation.

30. Id. (*d*, 47). Section of the Palisade trap at Weehawken, N. J.

31. Id. (*d*, 42). Ideal section of intrusive trap sheet. The descending branches seem to be of improbable occurrence.

5. GENERAL DISCUSSION.

Origin of the Triassic Estuaries. — The small number of Triassic trough-deposits and their absence from the western half of our Eastern mountains go to show that in the making of the Appalachians the synclinals were not, as a rule, absolutely depressed, but on the contrary took part in the general elevation, and rose with the rest of the strata, although to a less height than the anticlinals: as they were continually rising above drainage level, they very seldom or never served as troughs for the accumulation of deposits. But, on the other hand, the estuaries or troughs in which the Triassic strata were deposited must have been absolutely depressed below their previous levels; and it seems reasonable to suppose that the remarkable relation existing between the trap and sandstone areas, so often alluded to, must be mechanically dependent on this downfolding or absolute depression of the estuaries; for here alone where there is evidence of absolute local depression are the only post-carboniferous eruptions of trap to be found from the Green Mountains to Alabama. That this may be truly a relation of cause and effect is made the more probable by the evidence given in the following pages that much of the trap, if not all, was ejected during the downfolding and filling in of the troughs.

Professor Dana (*e*, 113) considers that the subsidence which ended in the post-Triassic eruptions was slow, and not more than five thousand feet, and that it caused in the end only small displacements of strata, wholly inadequate to cause the fusion and ejection of deep-lying rocks from which the traps were derived. He further instances the Green Mountains as a region where the folding was much stronger, and yet where no eruptions but only metamorphism took place, and takes this as arguing against the possibility that the moderate Triassic disturbance was the cause of the fusion and ejection of the traps.

However it may be with the fusion, I must differ from this opinion concerning the eruptions; it seems best, in view of what has been stated above, to suppose that the Triassic disturbance was directly and causally connected with the fact and act of the eruptions. The occurrence of absolute depression in the slightly disturbed Triassic troughs seems reason enough for mechanical eruptions taking place here, although absent elsewhere in regions of greater disturbance but general absolute elevation.

Origin and Deposition of the Triassic Strata. — There seems to be no sufficient reason to look upon these stratified deposits as very abnormal in their origin. Their material was derived from the highlands adjoining either side of their estuaries of lakes of deposit, and whatever the agent of importation — glaciers, streams, waves, or tides — the layers were probably coarser along the shores, finer in mid-water, and all essentially horizontal when deposited. It is noteworthy that those who look on the present dip as the result of original oblique deposition took this ground less from direct evidence in favor of anything so extraordinary, than from the hope of escaping from what seemed a greater difficulty; namely, the tilting to a (supposed) constant dip in one direction in each monoclinal belt.

In addition to the great improbability of the theory of oblique deposition, and its mechanical difficulties of one sort and another, it has to explain why very nearly all the detritus should have been derived from only one side of each estuary; and this in the face of the frequent occurrence of heavy conglomerates of local derivation on the other side. With the coarse material in the conglomerates, there must have been introduced a great quantity of finer detritus, which was carried farther from shore: how could this have been deposited dipping so uniformly towards its origin? The general absence of conglomerates along the outcrop sides of the estuaries, appealed to by Russell (*c*, 231–238, 251) as evidence of open water and not of shore line there, is partly and perhaps sufficiently explained by the fact that the outcrop side must have lost a large share of its original mass on account of its elevation and erosion. But it should be remembered that conglomerates or coarse sandstones of local origin do occur on the outcrop sides of the belts. Such are mentioned by Percival (430), Cook (*b*, 336; *c*, 31, 34), H. D. Rogers (*g*, 669, 677, 679, 760), and Kerr (*b*, 141). An example of pebbles found on one side of a Triassic belt and derived from the other, is given by Wurtz (100): he describes fragments in the sandstone beneath the Palisades coming from Green Pond Mountain, which stands northwest of the Triassic area. Further detailed study on the position and source of these conglomerates is much needed in order finally to prove or disprove the theories above mentioned.

The conditions and order of origin of the various strata, — conglomerate, sandstone, shale, limestone, and coal, — their even, cross-bedded, and ripple-marked structure, and the causes that brought about a change from one to another in this series, cannot be determined with any definiteness until the strata are better co-ordinated than they are at present.

I believe that in Connecticut and elsewhere there are repeated outcrops of the same beds, produced by faults as described below; but their identification is now a difficult matter. Microscopic analysis and detailed study by local observers will do much to solve this difficulty.

Composition of the Trap. — The composition of the eruptive rocks in the Triassic belts is not discussed here, as the present work relates to their physical characters. For this reason, the general term trap is employed throughout. Many names have been previously used, — whin, greenstone, trap, basalt, sienitic basalt, diorite, trachyte, dolerite, and diabase; but the last two would seem the more proper ones, judging by mineralogical composition. Chemical analyses and microscopic examinations of the trap from various localities have been made by Cook, E. S. Dana, Frazer, Hawes, Schweitzer, and Wurtz. The following statement gives the limiting percentages of their results: —

Silica	45.8–53.4%
Alumina	12.5–20.4%
Iron oxides	7.8–21.2%

Magnesia, Lime, Soda, Potash, less than 10% each.

The minerals present are pyroxene, labradorite, and magnetite, with certain accessory species, and chlorite as a common product of alteration. E. S. Dana (391) and Hawes (*a*, 185) note an increase in hydratation and alteration in going eastward across the Connecticut. It is noticeable that the least modified traps are dikes or intruded sheets, and the most modified are overflows, according to the present determinations; thus Hawes describes East and West Rocks and the Jersey City traps as dolerites, and the Saltonstall and Durham Mountains (Conn.) as diabases: Mount Holyoke gives an exception to this apparent rule, as it is classed under the dolerites, although it is certainly an overflow. The two authors above named considered all the trap as intrusive, and consequently did not perceive the natural relationship between conditions of origin and composition, as here suggested.

Relations of the Trap and Sandstone. — Two views as to the origin of the trap sheets have been discussed. According to one, they are considered eruptive across or between the sandstone layers, and more or less active in aiding the breaking, tilting, consolidating, and coloring of the strata, after the period of deposition had ceased. The other view looks on the trap sheets as younger than the sandstones below, and older than those above them; or, as it may be stated, the sandstones and traps are geologically contemporaneous; the sheets are old lava overflows buried under strata of later date than their eruption.

The following review, arranged by localities, beginning in the northeast, will give an idea of the various opinions that have been held.

In 1833, Jackson and Alger (*b*, 276) described the Nova Scotia trap along the Bay of Fundy as "an immense dike, thrown up from beneath the sandstone through some vast and continuous rent, produced by the sudden eruptive upheaving of its strata, which allowed it to spread out laterally only to a very limited extent." In 1846, Gesner included the same traps under the heading "Intrusive Igneous Rocks."

In 1848, Principal Dawson in describing these sheets said (58) that volcanic action "brought to the surface great quantities of melted rock, without disturbing or altering the soft arenaceous beds through which it has been poured, and whose surface it has overflowed." This is quoted in his Acadian Geology, 1868.

Bailey and Matthew mention stratified columnar and vesicular traps and trap conglomerates on Grand Manan; but further speak of the traps as intrusive (219, 220).

For Massachusetts, Hitchcock's first section (1818) shows the trap as a vertical dike breaking across the sandstones; this was soon changed (1823) and the trap and sandstone were described as in alternate beds (*b*, 48), separating the old red sandstone on the west from the coal formation on the east. In 1833, he described the conglomerate on the back of Mounts Tom and Holyoke, consisting of "angular and rounded masses of trap and sandstone, with a cement of the same materials," and concluded that some of the trap must have occurred as a contemporaneous overflow (*d*, 211). In 1844, the same conglomerate is ascribed to small precursory outbursts during the formation of the sandstone; but the larger ridges are considered intrusive and of later date. In 1858, he decides that all the Massachusetts trap is of overflow origin, as will be referred to below.

Lyell was shown the trap conglomerate on the back of Mount Tom by Hitchcock, and inferred "that there were eruptions of trap, accompanied by upheaval and partial denudation, during the deposition of the red sandstone" (*a*, 794). Leconte and Walling both adopt Hitchcock's final view, and it is recently confirmed by Emerson.

The rocks in Connecticut have given rise to other opinions. The elder Silliman held that the trap was eruptive, but did not reach the surface (1810–1830); his observations were mostly made when it was still discussed whether the trap might not be of aqueous origin. Cooper took strong ground in favor of the igneous origin of the trap, but did not concern himself with the manner of its eruption: he implies, however, a belief in overflows (240), though he quotes no decisive observation in this direction. Smith considered the trap eruptive over the tilted layers of the secondary strata (225, 227), and Chapin represented all the ridges about Wallingford as vertical dikes (fig. 8).

Percival states that the traps "have obviously the character of intrusive rocks of igneous origin," which exerted "apparently a controlling influence" in determining the arrangement of the sandstone (10, 11). The trap occurs in dikes and ridges; the dikes are small; the ridges are steep on one side, and on the other are frequently overlaid by sandstone, "thus apparently forming interstratified masses or inclined dikes." "In some instances, where the middle portion of a ridge appears thus interposed, or merely as an overlying mass, its extremities appear as distinct vertical dikes." "The ridge and the dike may thus be regarded only as modifications of the same arrangement." (300.) His use of the term "volcanic" (as 311) does not seem to imply that the eruptive rocks ever reached the surface: nor does "cotemporary formation" (299, 321) seem by the context to indicate the contemporaneous origin of the traps as used in this article. He would apparently agree with those who considered the trap eruptive after the making of the sandstone, often appearing between its layers and strongly affecting its position. The younger Silliman at first (1842) thought the sandstones tilted by the intrusion of the trap, but later reported to the American association of geologists, in 1844, that the sandstone had been deposited as now standing, and that the trap had been intruded without disturbance and had seldom reached the surface. Whelpley held similar opinions.

Professor Dana (*b*, 430) refers to Hitchcock's observations on the back of Mount Tom, and adds, "But after an examination of the region, the author regards it as more probable that the appearance of scoria is owing to an escape of steam laterally from between the opened strata during the ejection of the trap of the adjoining mountain." In the later editions of his Manual, he makes no mention of overflows. He states that the trap "has come up through fissures in the sandstone which varied from a few inches to three hundred feet or more in breadth. In many cases, it has made its way out by opening the layers of sandstone, and in such cases it stands with a bold front, facing in the direction toward which it thus ascended." (*c*, 419; also *d*, 46.) "The manner in which the trap at its eruption has sometimes separated the layers of sandstone, and in this way escaped to the surface, instead of coming up through the fissures simply, shows that the rock had been tilted extensively before the ejection." (*c*, 421.)

Akerly did not decide between the igneous or aqueous origin of the trap of the Palisades (62).

For New Jersey, H. D. Rogers wrote in 1836 that the molten trap had burst up through nearly parallel fissures, after the sandstone had been tilted : the eruption caused no further change in the position of the strata, but produced certain changes in their contents and structure (*a*, 160): and in 1840, "the protrusion of the trap, the formation and deposition of the conglomerate, and the elevation and final drainage of the whole red sandstone basin, have hardly been consecutive phenomena, so nearly simultaneous appear to have been these changes." (*c*, 171.) Cook considers the trap sheets intrusive. (*b*, 176, 200, 337; *c*, 32, 34.) Russell gives good evidence of the intrusive nature of the Palisade sheet (*d*), and claims to have proved the same origin for the First Newark Mountain (*a*). Wurtz regards the Palisade sheet as metamorphosed in place from sediments; he is doubtful if this origin apply to the Newark Mountain as well (101).

Pennsylvania gives so few good opportunities for observation, that little has been written about its trap sheets and dikes, though they are extensive and numerous. Many are omitted from the State Geological Map, 1858. Farther south, dikes seem much commoner than sheets; and so far as I have learned, there have been only two suggestions of contemporaneous overflow for any of the trap southwest of New Jersey. The first, by J. B. Gibson, was written in 1820 and published in 1825: "That the trap may have been deposited on the sandstone by a volcano before the present continent was elevated above the level of the sea, would be a more plausible supposition; but it would be altogether gratuitous." (Observations on the Trap Rocks of the Connewago Hills, 159.) The second was by H. D. Rogers, who wrote: "In certain cases the entire length of each middle secondary belt seems not to have been uplifted to the sea level before the commencement of the trappean eruptions; and those tracts which remained thus submerged are seen to contain, interstratified, as it were, with the later sedimentary deposits, those sandy volcanic tuffs or subaqueous sedimentary forms of trappean matter which constitute the link between the exclusively aqueous and igneous masses." (*g*, II. 762.) The context shows that such cases were regarded as very exceptional in Pennsylvania at least: no definite localities are given. "Overflow," as used by H. D. and W. B. Rogers (*g*, II. 670; *b*, 82) and Lesley (*a*, 133), seems to refer to eruptions after some erosion of the Triassic strata, so that the trap should lie unconformably on the sandstones: they all seem to regard the trap as post-Triassic, with slight exception.

Heinrich accepts the general view of post-Triassic intrusion for the Virginia traps (251). Fontaine writes that the "outpour" of fused rock occurred near the end of the period of deposit (29); but his attention is given more especially to the stratified rocks. Farther south than Virginia, there is no mention of anything but dikes in the sandstone.

It would thus seem that the overflow theory of the origin of the trap sheets has found its most pronounced supporters north of Connecticut.

There is theoretically no difficulty in distinguishing between the intrusive and overflow modes of origin, and the practical difficulty and difference of opinion above shown are probably to be explained by the rarity of good points of observation.

If the traps are intrusive, the sandstone above and below should show about equal signs of metamorphism; there might be fragments of sandstone in the trap, and such should be well baked, but there could be no fragments of trap in the sandstone; the trap might break across the sandstone layers, or send branches off from its main body; the upper surface of the trap should not be scoriaceous, especially in the thin layers, for if intrusive it must have been under almost as much pressure as the lower surface.

Examples of intrusive sheets elsewhere are described by the following authors:—

G. K. Gilbert. Geology of the Henry Mountains (Utah), 1877. The intrusive rock is not vesicular at all; no fragments from it occur in the overlying strata; metamorphism is marked as well above as below the intrusions. The name of *laccolite* was proposed by Gilbert for such masses of eruptive rock, and it may be applied to the Triassic intrusions as well. The laccolites of the West still retain their original horizontal position: those of the East have been tilted since intrusion.

Other less detailed mentions of intruded sheets may be found in the Annual Reports of the Geological Survey of the Territories, 1873, 186 (Marvine), 234 (Peale); 1874, 64 (Holmes), 219 (Endlich); 1875, 60, 95 (Peale), 268 (Holmes); 1876, 194 (Holmes): in the Bulletin of the same Survey, III. 1877, 551–564 (Peale).

A. Geikie. On the Tertiary Volcanic Rocks of the British Isles. Geol. Soc. Journ., XXVII., 1871, 279–310. The flows and intrusions of the island of Eigg are described in detail: the overflows have frequently been regarded as intrusions (292), but the two are easily separated by the difference in their metamorphic effects, and by the presence or absence of slaggy, amygdaloidal structure (281); the intrusions "are almost wholly confined to the lower portion of the volcanic series" (295).

A. Geikie. On the Carboniferous Volcanic Rocks of the Basin of the Firth of Forth. Edinb. Roy. Soc. Trans., XXIX., 1879, 437–518. Both intrusions and overflows are again recognized; in the former, a cellular or amygdaloidal texture is hardly to be observed, and never when they are largely crystalline (475); in the latter, amygdaloids are common (481).

If the trap sheets are old lava-overflows, there must of course be supply dikes, by which the sheets were fed, and these dikes must cut across and bake and be younger than all the strata they pass through, but their cross-section will probably be small compared to the area of the overflows; the sheets will be rather closely conformable to the strata over which they flow, though, as might be expected, their creeping advance while yet molten may have produced some disturbance, and they may contain sandstone fragments; only the previously formed sandstone beneath them can be baked; the upper and lower surface of the flow should differ as in modern lava flows, the upper being more vesicular and uneven than the lower; one flow may cover another; the compact lavas may be preceded or followed by tufaceous or fragmentary deposits; the overlying sandstone must lie conformably on the uneven surface of the lava, adapting itself to all inequalities, and gradually filling them to an even surface; it may often contain volcanic sand or fragments of lava.

Overflow sheets are much more common than intrusions; the following references will lead to descriptions of some of the more notable.

K. C. v. Leonhard. Die Basalt-Gebilde, 1832. This work serves well as a guide to the older European observations on eruptive rocks. Both overflow and intruded sheets are recognized; the former are described as scoriaceous on the surface, while the latter are generally dense, because gas bubbles could not expand in their heavily compressed mass (I. 473); but in speaking of the baking in the adjoining strata (II. 230), the author does not clearly state the different effects of the two kinds of sheets.

J. W. Dawson. On the Lower Carboniferous Rocks, or Gypsiferous Formation of Nova Scotia. Geol. Soc. Journ., I., 1845, (29–31). Several beds of trap conformably interbedded with the adjoining strata; the trap is dense below, amygdaloidal above, and its fragments are found in an overlying conglomerate. (See also *e*, 316, and section, 125; *h*, 49.)

J. S. Newberry. Pacific Railroad Reports, Vol. VI., 1857, ch. vi., vii., the overflows of the Columbia basin. Geological Report of the Colorado River Exploring Expedition, 1861; many observations.

G. P. Scrope. The Geology and Extinct Volcanoes of Central France, 1858, 14.

Medlicott and Blanford. Geology of India, 1879, I. 299. Amygdaloids are very common, especially in the upper part of the various flows.

M. E. Wadsworth. Geology of the Iron and Copper Districts of Lake Superior. Bulletin Museum Comp. Zoöl. Cambridge, VII., 1880, 109–113. The trap sheets are amygdaloidal at the upper surface: they were first shown to be overflows by Foster and Whitney, in 1850, but various opinions have since been expressed concerning them.

In the Western Territories, lava overflows have been very common, and have covered vast extents of country. They are mentioned in nearly all the Western Survey Reports, but their overflow origin is as a rule so evident that few special descriptions are given of the characters that serve our needs of comparison. The following may be referred to from among many others: King, 40th Parallel Survey, I. ch. vii. sec. v. Geol. Survey of the Territories, 1874, 172 (Peale); 1875, 145 (Endlich). C. E. Dutton, Geology of the High Plateaus of Utah, 1880, ch. iii.

The above means of distinction between intrusions and overflows are almost self-evident; but they have seldom been definitely stated in connection with our Triassic traps, and have often been entirely overlooked. The earlier studies of the traps were made when the controversy between the Vulcanists and Neptunists was still unsettled; it was sufficient then to show that the traps were igneous, not aqueous. But later than this, and down even to recent dates, observations on the traps seldom give secure basis for statement of their mode of origin, for the essential and critical points for observation have been very generally neglected. In many cases the older observers gave no special attention to this physical phase of the question; their work being directed to some other of the many difficulties that the Triassic rocks present; and hence from their accounts it is impossible to discover how the trap is related to the adjoining rocks. Even Percival's remarkably painstaking and accurate description of the Connecticut traps is often indeterminate as to their origin; it is greatly to be regretted that he had not better opportunity to publish what he had learned, in addition to simple descriptions.

The rare exposure of contact lines is extremely provoking: in the Connecticut valley alone their combined length must amount to many hundred miles, but so universal is the drift and talus covering, that one seldom finds more than a few feet of "junction" exposed. And this is especially the case for the more important upper contact with the sandstone on the back of the trap; for during the ages in which these rocks have been eroded, they undoubtedly stood frequently or always at a higher level above the sea than at present; the soft beds were deeply worn away, and are now buried under the clays and sands of post-glacial weathering or of glacial deposit. Upper contacts are everywhere rare. Lower contacts are not very uncommon in Massachusetts, Connecticut, and New Jersey; but nearly all contacts are hidden in Pennsylvania and farther south. The discovery and description of the junction of the trap with sandstone above and below it afford excellent field for local observations in all the Triassic belts.

The observations of the past summer, as detailed in the preceding pages, give examples of nearly all the points of evidence required to prove an intrusive or an overflow origin of the trap sheets. The localities where the best evidence of overflow sheets was found are: — Conformable, unbaked sandstone on the trap, or fragments of trap in the overlying sandstone, at Turner's Falls; on the back of Mount Tom and its posterior ridge; and at Feltville, on the back of the First Newark Mountain. Tufa deposit with fragments or bombs of trap, under the second posterior ridge, Turner's Falls. A second lava-flow resting on the uneven amygdaloidal surface of an earlier one, at West Springfield. Percival mentions a trap breccia or conglomerate at several points in Connecticut. Dawson represents a large mass of these fragmental trap deposits in his Nova Scotia section.

Three distinct forms of occurrence must be admitted for these traps: first, the feeders, or supply dikes; second, the intruded sheets, generally lying evenly between the enclosing layers; third, the overflow sheets. The second and third forms are generally closely alike in their present topographic features, and can be distinguished only by detailed observation. Even in the best known districts, there is room for much work of this kind.

Trap Dikes. — Under this heading will be included only those trap masses that have a greater extension across the sandstone layers than parallel to them. They have been observed as follows: —

Dawson and Harrington note a single occurrence of trap on Prince Edward Island in a dike form; it is vesicular and scoriaceous in part, as well as dense and columnar (21).

Bailey and Matthew mention a dike in the Triassic of Grand Manan (221).

Hitchcock says there are no well-characterized dikes in the Massachusetts sandstones (*e*, 655); the only possible case of the kind was found on the south side of Mount Tom, near a saw-mill on a stream, not far from the main road three miles below Northampton (*e*, 656).*

In Connecticut dikes are comparatively common. The first examples recognized were described and figured by Hitchcock in 1823 (*b*, 56); they are in East Haven, eight narrow dikes within four hundred feet. (See figs. 2 and 44.) Chapin was the first to describe and figure some of the numerous and irregular dikes about Wallingford in 1835 (fig. 10). Percival refers to all of these, and adds many others; but it seems that he sometimes applied the word *dike* to sheets, and therefore we cannot say how many of his examples would come within our limitation. Pine and Mill Rocks at New Haven (G) are the largest dikes observed in the State.

Mather gives one or two examples from the face of the Palisades (279, 282, here copied, figs. 11, 12).

Cook finds only two dikes in New Jersey; one near Blackwell's Mills, on the east side of the Delaware and Raritan Canal; the other in a road cut beyond the Flemington copper mine; but he thinks it probable that many others lie hidden below surface drift (*b*, 204; *a*). He later says there are many places where the trap can be seen cutting across the stratified rocks, as by Hook Mountain, Palisade range (*c*, 32).

In Pennsylvania and beyond, dikes become more common. H. D. Rogers figures two examples (here copied, figs. 21, 22), and on the State map (1858) a number are represented within and without the sandstone belt: of the latter, the most remarkable is the long dike discovered by Henderson, which extends some eighteen miles, across the Juniata and Susquehanna near their junction. Frazer describes the dikes in Lancaster and the adjoining counties as so numerous and so difficult to trace that he was unable to represent them all on his map (*c*, 27); he says, also, "The outflow of trap probably followed one or more of the planes of cleavage, of which these rocks are full" (*b*, 325; his sections showing dikes are cautiously drawn without contact lines: compare extract below, under Intruded Sheets).

W. B. Rogers mentions dikes cutting across the sandstones in Virginia (*b*, 82), and Heinrich writes that, "Penetrating the sedimentary rocks, igneous rocks are occasionally met with in the form of dikes" (244, also 250, 263).

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* Since writing the above, Professor C. H. Hitchcock tells me that he has seen one or two small vertical dikes cutting the sandstone in a quarry on the southwest slope of Mount Holyoke about half a mile from the Connecticut, — the only examples of the kind known to him in the State.

Lyell shows a dike in his section of the Richmond coal field (*c*, 271; our figure 17). Olmsted (*c*, 236) and E. Mitchell speak of trap dikes in North Carolina. Emmons does not describe or figure any sheets, but shows several dikes on his sections (*d*; our figure 24). Kerr states that the sandstones are everywhere intersected in various directions by dikes of trap; their thickness varies from a few yards to two or three rods, and their length occasionally reaches several miles: the sandstones and shales are usually blackened for several feet or yards on either side of the dikes (*b*, 146); the dikes are usually transverse to the stratification (*a*, 48).

It would seem from this review that dikes are rare in Nova Scotia, in Massachusetts and Northern Connecticut, and in New Jersey; while they are common in Southern Connecticut, in Pennsylvania, and farther south. They are of all sizes up to two hundred feet, Mill Rock and Pine Rock just north of New Haven being the largest well-known examples. They are, as a rule, dense and compact, with a rough columnar structure at right angles to the sides; some are reported as amygdaloidal, but such are clearly exceptional; their vesicles are very likely not of gas-bubble origin. The sides of the dikes are not smooth, like the sides of most of the dikes in the old jointed slates about Boston, but are more or less irregular or even ragged (fig. 45); implying that there were no joints to guide their fissures. It should be noted, however, that some of the looser sandstone is still almost without joints, and in such cases this point of evidence is of no value. Their metamorphic effects are not far reaching so far as observed: a dike ten feet wide bakes the sandstone for a foot; a hundred-foot dike has some effect ten or twelve feet away. None of these dikes have clearly the form of "necks" or "chimneys," such as are described by A. Geikie about the Firth of Forth (Edinb. Roy. Soc. Trans., XXIX., 1879, 468).

Intruded Trap Sheets. — A number of sheets named in the following list cannot be regarded as fully proven to be of intrusive origin: the evidence for Pennsylvania and the States farther south is very incomplete.

There seem to be no intruded sheets north of Middle Connecticut. Farther south, near New Haven, East and West Rocks (G) and the northern continuation of the latter have long been rightly regarded as intrusions. Smaller examples occur at Wallingford (F), and doubtless many more may be found.

Percival's descriptions make it very probable that all his western line of elevation from East and West Rocks at New Haven north to Southington are intrusive traps. In evidence of this, we may note the general absence of amygdaloid here (mentioned once on 403), and the frequent mention of indurated sandstones above as well as below the trap. The sandstone near the trap by East Rock (W. S. I. 1)* "is remarkably indurated to an unusual width" (395). Two points on the back of East Rock show "highly indurated sandstone" bordering the trap (396). Mill Rock (W. S. I. 2) is a dike rather than a sheet, and is bordered by "light gray very indurated coarse sandstone" (396). West Rock (W. S. I. 4) is overlaid or bordered on the east by indurated sandstone (399). The dikes or ridges of W. S. I. 7 are bordered by "singularly altered and indurated" sandstone (401). Roaring Brook shows indurated sandstone on the back of W. S. II. (403). "At different points, in connection with the western line of trap," dark purple, black, and bright indurated sandstones are found (437). Professor Dana classes East and West Rock, Mount Carmel, and the Meriden Hills with the dikes of Pine and Mill Rock, as trap "that came up melted through wide fissures in the sandstones and subjacent rocks" (*d*, 46).

The Palisades give the largest example of intrusion: this origin was first well proven for them by Russell (*d*; see also our observations, H, J); Emmons noted, a number of years ago, that branching intrusions occurred in the sandstones below (*b*, 200; his figure is here copied, 16). Smaller sheets are found in New Jersey at Martin's Dock (N), and on the Delaware (O); whether the large coarse trap masses by Lambertville (P) are dikes or sheets, I cannot fully decide; but they are not overflows. Cook inclines to the intrusive origin of all of these (*b*, 176, 200); he mentions the occurrence of transverse dikes by Hook Mountain, the north end of the Palisade Range (*c*, 32), which would seem to correspond to the large dikes by West Rock, Conn. H. D. Rogers's sections represent intruded sheets in the Pennsylvania sandstones near the surface (here copied, fig. 23); and Frazer says of the traps about Lancaster County, "As a general rule in this region, their dip corresponds to that of the beds between which they were poured out" (*b*, 318; compare with the quotation above, under Dikes).

W. B. Rogers describes the trap in Virginia as "not unfrequently entering between the layers of sedimentary rock, or pouring out and overspreading them at the top" (*b*, 82); and Lyell writes of the trap in the Richmond coal field that it, "although intrusive, has often here, as is so common elsewhere, made its way between the strata like a conformable deposit." But all these latter references are inconclusive as to intrusions or overflows; they leave the question open for further work.

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* The notation used by Percival.

The trap sheets which are definitely determined to be intrusive show no vesicular structure at any point so far as I have seen them; they are dense throughout, fine at the margins and very coarse in the centre of the larger sheets. Their metamorphic effect on the adjoining sandstones is very marked, as will be described below. The even intrusion of these sheets between shaly or sandy strata is very remarkable. At Martin's Dock and Point Pleasant Station, N. J. (N, O, figs. 51, 52), where this is best shown, trap sheets of various thicknesses, from two to twenty feet, are seen evenly interposed between the strata above and below them for fifty or more feet, without breaking across the layers at any point: in two cases the slaty partings between adjoining trap sheets are less than one foot thick, and yet are continuous for over fifty feet. From this it must be supposed that the molten trap was injected slowly, and that it acted as a liquid wedge, prying open a passage for itself along the planes of easiest breakage that could be found: where two sheets are close together, one was probably intruded after the other. Still it is surprising that any rock could break so evenly as the Triassic strata are thus proved to have broken.

It is not a little interesting to discover that the largest clearly intrusive sheets, the West Rock range and the Palisades, are found on the outcrop side of their respective sandstone belts; they are near what would be the bottom of the sandstone series if the entire formation had received a single monoclinal tilting. The intrusions on the Delaware are also near the base of the formation, as is shown by the appearance of the Matinal limestone not far from them. The probable cause of this is suggested below.

The date of these intrusions is indeterminate. It cannot be fully shown when they took place; whether at about the time of the overflows, that is, the latter half of the Triassic time, or whether their intrusion came later, when deposition was stopped by upheaval and dislocation; but the latter is the more common view.

Professor Dana has already been quoted as taking the position of the trap sheets as evidence that their intrusion came after the sandstones had been tilted extensively (*c*, 421). But the laccolites of the Henry Mountains, Utah, as described by Gilbert, and similar intrusive rocks in Colorado described by Peale (referred to above) lie between horizontal strata; it is therefere not necessary that the sandstones should have been tilted in order that the trap might be forced in between its layers. Professor Dana further argues, from the fact that the trap columns on the face of the ridges are at right angles to the sandstone layers, that "there was a tilting of the strata in progress, before the final breaking and ejections" (*c*, 421). This is also inconclusive; for the same relative position of columns and strata obtains in the sheets that overflowed on horizontal layers, the entire mass being tilted bodily afterwards. We must therefore differ from the conclusion that the eruptions of the trap were necessarily the "closing events of the sandstone period," or that they took place in "a succeeding epoch" (*c*, 421). The overflow sheets were certainly of earlier formation: the intruded sheets may have been so as well.

Russell states that the outbursts of trap occurred after the sedimentary rocks had been consolidated and upheaved, and at the time when the post-Triassic elevation culminated. His evidence for this view is theoretical (*c*, 245, 251) and is seriously weakened by the occurrence of overflows. The generalized section that he gives for the Palisade sheet (*d*, here copied, fig. 31) shows some down-branching dikes of problematic occurrence. Cook classes all the traps as eruptive after the deposition of the sandstones and shales (*c*, 32).

The evidence which points to an early date for the eruption of the intruded sheets is, first, the ragged line of contact with the sandstones where they are broken across; this, as has already been mentioned under the dikes, indicates an eruption before the making of joint planes, and consequently before the tilting; but it is not final or conclusive. Second, the occurrence of intrusions chiefly on the outcrop side of the sandstone belts, or, in other words, near the base of the formation; the only cause that I can suggest for such a limitation of position is that these laccolitic intrusions could only form at a considerable depth, and under considerable pressure, and were therefore placed near the bottom of the sandstones before the latter were tilted: if the intrusions had taken place after the tilting, they might break out at one point as well as another, and would not be likely to have so peculiar a restriction as that above noted. Third, the intruded sheets have the same crescentic form as the overflows; and this, as will be shown farther on, results from folding after the eruptions: while it is possible that the intrusions were guided into their curved line of outcrop by the gently folded strata, it seems more probable that all were folded together.

But, as stated above, this question is at present indeterminate; the above suggestions may serve to counterbalance opinions on the other side of the question, but not to settle the matter. It remains with a number of other points, notably the monoclinal structure, open for further observation.

The force which caused the intrusion of these sheets can hardly have been the expansion of vapors and gases, which plays so important a part in modern volcanoes; for evidence of such expansion (vesicular structure) is wanting. It was therefore more likely mechanical, and connected as already suggested with the downfolding of the troughs rather than with the subsequent elevation and tilting of the sandstones. So far as this holds good, it also points to a Triassic date for the intrusions as well as for the overflows.

Overflow Trap Sheets. — By far the greater number of trap sheets seem to be of overflow origin. The proof of this origin is more or less completely established for the following examples.

The high trap cliffs of the Bay of Fundy are described by Dawson as overflows, but he gives no account of their upper contacts, and his section (here copied, fig. 18) shows much more irregularity than any that I have found in Massachusetts and farther south. But amygdaloids are very common in Nova Scotia, and these seem limited to overflow sheets. On Grand Manan the trap and amygdaloidal beds conform to the adjoining sandstones (Bailey and Matthew, Verrill). The Connecticut valley gives many examples. Farthest north is Deerfield Mountain, as recently described by Emerson and as represented in this paper (A); the long range beginning at Belchertown, Mass., including Mounts Tom (B) and Holyoke, and extending to the Hanging Hills (E) by Meriden, Conn., has been fully shown to be an overflow in its northern part, and it can hardly be of other origin farther south. Its lateral ridges are probably all overflows as well. Hitchcock's observations applied to the posterior ridge on the back of Mount Tom, and should have left no doubt of its mode of formation.

In Connecticut, much observation is still necessary to decide finally on the origin of the numerous ridges. The evidence that favors the intrusive origin of all Percival's western line of elevation has already been stated. Equally good evidence may be found to show that all the large and most of the small sheets of the eastern lines of elevation are overflows. The frequent occurrence of indurated sandstones, and the general absence of amygdaloids, in the west, contrast strongly with the lack of evidence of distinct metamorphism, and the frequent mention of amygdaloids, and trap and amygdaloid conglomerates, in the east. Toket Mountain (E. II.) is described as dense trap at the base, amygdaloidal at the top, and overlaid by friable red shale (Percival, 338). Lamentation Mountain (E. III. 5) has swells of amygdaloid on the back, overlaid by shale (352). The anterior range is separated from the main range of Newgate Mountain (E. IV. **2**. 2) by a band of friable red shale (391). A part of A. 1, S. of E. II. shows a peculiar dark green trap conglomerate, accompanied by beds or dikes of amygdaloid and fine-grained trap (341). A conglomerate east of Saltonstall Lake contains fragments of a fine-grained light green sub-amygdaloidal trap, similar to that in P. 1 of E. I. (324). The ridge anterior to Lamentation Mountain is partly composed of a peculiar trap conglomerate, or rather brecciated amygdaloid, distinctly parallel or stratified in its arrangement (365). Many similar extracts might be noted.

In New Jersey, I believe First Mountain to be proved an overflow by observations at Paterson and Feltville (L and M), although Russell takes the other view. As early as 1822, Cooper wrote that "this mass of floetz trap is poured over the old red sandstone" (240), but it is doubtful whether he had considered the possibility of its intrusion. Second Mountain is probably also an overflow, as its sheet is very amygdaloidal and irregular in structure near the under surface at Little Falls, and its effect on the underlying sandstone is very slight; but its upper contact has not yet been described. Cook mentions pebbles of trap in the sandstone *beneath* the First Mountain (*b*, 337), but later says that no fragments of trap are found in any of the stratified beds (*c*, 34).

There are no decisive observations of contact for the trap sheets of Pennsylvania and the States farther south. H. D. Rogers speaks indefinitely of "overflowed" trap (*g*, 670), of amygdaloid near the borders of certain of the larger dikes (*g*, 671), and of "sandy volcanic tuffs" and "trap shales" interstratified with the sandstones, mostly in Nova Scotia, some in Connecticut and the Middle States (*g*, 762). Lesley's general section (copied in fig. 19) shows "the original sea, the lava and its vent, the manner in which it lifted the new red layers at its outburst, so soon as it was near enough the surface to do so, and overflowed them above" (*a*, 133), but evidence to prove this sequence of events is wanting.

Heinrich mentions that amygdaloids are found in the Virginia traps (244).

The sheets which are proved by their appearance at the contacts to be overflows have the following characters: they produce very little metamorphic effect on the underlying strata; they often show some vesicular structure near the base, sometimes within the mass, and are always very amygdaloidal at the upper surface. It cannot be said that amygdaloids occur only in the overflow sheets, for they are reported in some dikes, and in rare instances in intrusions; but the vesicular structure is as frequent in the overflows as it is rare elsewhere.

Percival noted that the amygdaloids are generally found in the lateral portions of the trap ranges, and occasionally make a large part of the lateral ridges (315); Hitchcock wrote that amygdaloids occupy "the easterly [i. e. posterior or upper] part of the ridges wherever I have examined them" (*e*, 645); and Rogers, that amygdaloids are common "near the borders of certain of the larger dikes" (*g*, 671).

The occurrence and position of the amygdaloid has been variously explained. Jackson and Alger (*b*, 265) thought this texture resulted from the combination of the trap with sandstone and shale. Rogers stated that the amygdaloid occurred "in immediate contact with the altered red shale, by the reaction of the trap upon which this amygdaloidal character has been acquired" (*g*, 761, 763). Cook says that if the cooling of the traps had been "rapid and not under much pressure, they would be more or less cellular" (*b*, 215). Professor Dana considers all the original trap to have been equally anhydrous at its deep source, and to become vesicular by the expansion of steam formed wherever water was met in the process of eruption (*e*, 107). E. S. Dana and Hawes accept this cause.

Several of these explanations are undoubtedly true and possible, but they do not show why the overflows should always be amygdaloidal on the back, and why the intrusions should so generally be compact. It seems most probable that the vesicular texture was produced in these old traps as it is in modern lavas; not so much by meeting water during their eruption, as on account of a decrease of pressure which allowed the occluded gases and vapors to separate from the surface of the overflowing molten mass (Dawson, *d*, 63; *e*, 87). The difference in the composition of the eastern and western traps found by E. S. Dana and Hawes in lower Connecticut has already been referred to as resulting naturally from the better chance the eastern traps have had for alteration.

The area marked by some of the larger ranges is very considerable. The Mount Tom — Hanging Hills range has a front sixty-five miles long, and, judging by the curves at either end, its breadth must be six miles, giving an area of nearly four hundred square miles. If the several loops down as far as Saltonstall Lake all belong to the same sheet, broken by faults, as is suggested below, then the length and breadth would be much increased, and the area might be over seven hundred square miles. The Newark Mountains in New Jersey would in the same way have an area of above three hundred square miles.

But it is not by any means proven that these sheets are the product of single eruptions. The heavy trap which forms Mount Tom (B) decreases in thickness or disappears entirely in going south, and the range is continued for a time by a varying number of smaller sheets. So at Turner's Falls (A), the southward ending of the first and second posterior ridges seems as well explained by the giving out of the trap at the edge of its flow-area, as by the faulting suggested by Emerson. At West Springfield (C), the composite structure of the second posterior trap is well shown. In New Jersey the irregularities in the columnar structure of the Newark Mountains at Paterson and Little Falls (L) may be perhaps explained by supposing each mountain to be the product of several consecutive flows. It seems, therefore, probable that the long trap ranges represent a period of volcanic activity, rather than a single violent outburst, preceded and followed by periods of shorter or less intense activity represented by the anterior and posterior ridges. This is shown in Connecticut far better than anywhere else, and is beautifully illustrated by Percival's remarkable map.

The importance of the overflow trap ranges as marking horizons in the deposit of the sandstones will be referred to later.

*Effect of the Trap on the Sandstone.** — A metamorphic effect is generally attributed to the trap, by which the sandstone in its neighborhood has been indurated and changed in color to a greater or less extent. The most exaggerated form of this idea ascribed the general red color of the whole formation to the effects of trap heat (Hitchcock, *d*, 242; see also Percival, 430, and Dana, *c*, 420); but as red sandstones are common in other regions far from any contemporaneous or subsequent igneous action, it is more probable that their color here as well as there is essentially due to conditions of weathering at the time of deposit. Whether the contemporaneous volcanic action in the Connecticut valley aided the coloring of the sandstones or not, is difficult to say; for bright colored strata are found far from and near to the horizons of the volcanic rocks. But, as a general rule, the baked strata near the trap are not so red as the unaltered layers farther away. Above and below the Palisade trap sheet (H), the rocks were black, gray, or dull reddish-brown, but not strong or bright red as is common elsewhere. Under Mount Tom (B), the sandstones near and at the contact were gray or dull greenish-gray. Along the Delaware (O, P), the layers nearest the trap sheets or masses were black or dark gray; the red strata appeared only several hundred feet on one side or the other, so far as seen: these last are the most extended effects of the trap that I found. In the West Springfield railroad cut (C), the baked sandstone for a quarter or half inch from the contact was almost white on fresh surfaces.

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* I have not yet had time to examine closely the mineralogical changes produced by the trap; some of these, as shown by specimens collected during the past summer, are very striking.

The absence of red color in strata near a contact has been noted by several observers. Silliman described the sandstone close under the trap of Rocky Hill by Hartford as gray or white (*e*, 125). Percival found that the sandstones near the trap were "sometimes discoloured greenish or brown, and at other times their usual reddish color is apparently discharged, leaving them nearly white" (319, also 436): in a few cases they are black or red (437). Lyell found some of the shales turned white below the traps of the Richmond coal field (*c*, 271). H. D. Rogers described the shales near the traps as dull brown or purple (*g*, 673, 678). The change to black color as a consequence of baking is mentioned by Cook (*b*, 206, 212) and Kerr (*b*, 147). In view of these facts, it is impossible to consider the prevailing color of the New Red Sandstone in any way dependent on the action of the trap after the deposit of the sandstones. How much effect the contemporaneous eruptions may have had upon weathering and color, is an open question.

In regard to the effect of the trap on the hardness of the sandstone the most excessive views were those of H. D. Rogers, who considered most of the good building sandstone in New Jersey hardened by baking (*c*, 157); and of Whelpley, who thought that the sandstones had covered a broad area in Connecticut, but had been preserved only near the trap, where it was hardened (62). But here, as before, it may be urged that as hard sandstones occur plentifully in regions free from eruptive rocks, it is more probable that variations in the hardness of the sandy and shaly Triassic strata, except those close to the trap, are due to the unequal action of the ordinary processes of consolidation. Whatever distinct hardening effect was produced by the trap, it generally extended but a short distance into the adjoining rocks, — probably in no case more than one hundred feet. Slight mineral alteration reached farther than any other notable change.

The marked difference between the effects of the intruded and the overflow sheets has already been pointed out. The Palisade trap (H, J) hardened the adjoining sandstones and shales very distinctly for twenty feet and probably farther, and in some of the more easily altered layers produced a marked crystalline structure: this was equally apparent at upper and lower contacts. On the other hand, the lower contact of the overflows shows a very slight change from the normal sandstone. Emerson describes the alteration under the Greenfield trap as extending only an inch from the contact, and the baking as reaching only a foot (196). Under Mount Tom (B), the baking reaches three feet or more. Under the First Mountain trap at Paterson (L), the alteration is distinct for several inches.

The different effects in these contrasted cases evidently depend on the manner and rate of cooling. The intruded sheets must have cooled slower, and entirely by conduction through the enclosing rocks, and hence produced more baking than the others. The difference in the baking effects of different intruded sheets can probably be largely referred to the variations in the composition and the amount of moisture present at the time of intrusion.

Tilting of the Sandstones and Traps. — The remarkable monoclinal structure of several of the Triassic belts has given rise to five suppositions: first, that the present is the original position of deposit; second, that the originally flat layers have been tilted into a monoclinal without faulting; third, that certain paired belts are lateral remnants of a broad, eroded anticlinal; fourth, that the present position is the result of repeated faults and moderate folds; fifth, that a tilting was in progress during the deposition (Cook, *b*, 174; *c*, 34). I am unable to give any evidence for or against this last proposition.

Before speaking of these theories we may note the structure of the several Triassic belts; for some of them do not present any very peculiar features in the position of their strata. On Prince Edward Island the formation shows repeated faint folds (Dawson and Harrington). Around the Bay of Fundy there is an unsymmetrical synclinal, with the greater visible part on the southeast. The Connecticut valley belt has a prevailing dip to the eastward, but with significant exceptions. The long strip from the Hudson extending almost continuously to the Dan River in North Carolina has a similarly prevailing dip to the northwest or west, but also with certain irregularities. The Richmond coal field is a synclinal, strongly faulted (W. B. Rogers and Heinrich). Two patches north and east of it, and the Deep River strip reaching into South Carolina, dip to the east or southeast (Heinrich and Kerr).

First Theory. — H. D. Rogers first thought that some external force was responsible for the tilting (*a*, 160), but soon replaced this supposition with the theory that the several sandstone belts from the Dan River to the Hudson had been deposited with their present oblique dip in a noble river that rose in the mountains of North Carolina and flowed northeast to the ocean about New York Bay; that the occasional reversal of dip was produced by eddies in the great current; and that the monoclinal theory was impossible because the great depth that it required for the sandstone was disproved by the visibility of the old foundation rocks at certain points within the Triassic belts (*b; c*, 166–171; *d; g*, 671, 761). Mather replaced the river by ocean currents, but otherwise accepted this explanation. Whelpley thought the large and small sandstone areas of Connecticut once connected by a general, oblique deposit, since eroded except where trap intrusions preserved it. This theory has gained few advocates. Oblique deposition on so large a scale and at so uniform a dip as sometimes occurs over large areas is impossible; and as has already been pointed out, the occurrence of plentiful conglomerates on the dip side of the sandstone belts is a strong argument against it. The unsymmetrical form of footprints, as if made on a sloping surface (H. D. Rogers, *d*), is too exceptional to be of much value (Hitchcock, *h*, 17). On the other hand, it need not be claimed that the layers were absolutely horizontal when formed. Some small share of their present dip may be original.

Second Theory. — The theory of anticlinal remnants was first proposed for North Carolina by Kerr, in 1874. It was extended by Bradley (289) to Connecticut and New Jersey, in 1876, and proposed for the same region independently by Russell, in 1878. Heinrich suggests a somewhat similar explanation for the several sandstone patches in Virginia (249), but later considers each estuary isolated (251). The objections to this theory are well set forth by Dana (*g*); it has the serious defect of resting on negative rather than positive evidence; it fails to explain the general absence of trap in the intermediate region, and the occurrence of such an isolated sandstone patch as that of Waterbury, Conn.; the amount of erosion it requires is something enormous; the occurrence of conglomerates along the outcrop side of the sandstone belts has already been mentioned as arguing against it. (See fig. 29.)

The Third Theory supposes the entire body of horizontal strata tilted to a uniform dip, and the upper parts worn off. This has been advocated by Hitchcock (*c*, 221, and later), partly by Cook (*b*, 174), and more recently and decidedly by Leconte (441). Besides the great thickness of strata that this supposition requires, and the enormous erosion it involves, not only of sandstones but of the older rocks on one side, the theory is based on the assumption that there is no faulting or reversal of dip; and this is not proven. If lack of visibility sufficed to prove the absence of faults, it might be said that there are none in Pennsylvania, Virginia, and Tennessee; for fault-planes are hardly ever seen there; they are lines of weakness, and are always covered with detritus. Their existence is known by the repetition of outcrops that they produce, and this test can hardly be applied as yet in the Triassic belts, for the beds there are, as a rule, too little varied to be recognized at their repeated appearances, if such occur. On the other hand, as may be inferred from the position of the intruded sheets, there is evidence that, however numerous the faults may be, they fail to bring up the lowermost strata; and the great sweep of the trap curves in New Jersey would indicate an approach to the simple monoclinal structure. These considerations would imply a great thickness for the sandstone. (See figs. 6 and 28.)

The Fourth Theory looks on the general monoclinal dip as the result of tilting with faulting and some slight folding, but is unable to explain the mechanism of the disturbance; and here with regret I must take my place. Much more observation is necessary before any detailed explanation of this peculiar disturbance can be made. It can now be said only that the disturbing force pretty surely was one of the latest manifestations of the Appalachian mountain-building, which began and had its greatest activity long before; and that the eruption of the trap had no important share in it. Here, as in so many other cases, the trap is relegated to a passive *rôle;* and as already suggested, its eruption was very probably a direct effect of the force which at one time depressed the Triassic troughs, and later deformed the rocks collected in them.

It is sometimes objected that it is mechanically impossible to fault a series of horizontal layers into repeated parallel monoclinals. In answer to this it should be urged that too little is still known of geological mechanism to make such apparent impossibilities of much importance; that faulted monoclinals of gentle dip have been found in the Western plateaus (see Dutton's sections of the High Plateaus of Utah), and of steeper dip in Tennessee (Safford's Geology of Tennessee); and that the Triassic monoclinals show not infrequent irregularity too great to be considered the result of eddies (as Rogers thought), and implying the presence of incipient folds.

As to the occurrence of faults, some of small throw are seen in Delany's Quarry above Holyoke (B), in the West Springfield railroad cut (C), and on the northern slope of Garret Rock, Paterson (L); slickensides are noted about New Haven, in the Jersey City cut, and in Goat Hill by Lambertville. Faults are also shown in the Richmond coal field synclinal by W. B. Rogers and Heinrich, and are suspected by Cook in New Jersey (*c*, 33). Further observation will surely discover others, either directly or by means of repeated outcrops. In this latter way a fault has been determined with a great degree of probability at Beckley, Conn. (D); and a similar one, but of much larger throw, very likely occurs west of Lamentation Mountain, Conn., with uplift on the east, so that the trap sheets seen in Lamentation and in the Hanging Hills are really parts of a single overflow. The evidence of this is the repetition of similar series of strata as described by Percival in the outcrop faces of the two mountains; in each there is sandstone at the base, then the amygdaloid of the anterior ridge, next a limestone at the bottom of a shale, and finally the heavy trap of the ridge line. As shown in fig. 43, the fault is about three thousand feet. It is obvious that a great saving is thus made in the thickness of the sandstone: a moderate depth of formation is made to cover a good breadth of country by its repeated rising to the surface; the layers do double duty, and the vast thickness supposed necessary on the monoclinal theory may be much reduced for Connecticut at least. Similar evidence makes it very probable that the same sheet of trap is repeated by faulting and folding southward from Lamentation Mountain in all the high ridges to that of Saltonstall Lake; but further observation is needed on this point.

We have already stated that the uniformity of dip in direction and amount has been exaggerated, especially by H. D. Rogers, who wrote that in the Connecticut valley there is "only one direction of the dip," and in New Jersey, Pennsylvania, and Virginia, "without exception the strata dip in only one direction" (*g*, 761; also 670). It was thus that he was forced to prefer the theory of original oblique deposition. But this artificial constraint vanishes when we recognize that flat folds with faults are perfectly indicated by the curved outlines of the trap ridges, and by the conformity of the sandstones to these curves; for the trap sheets that are shown to be overflows at once take the important position of distinct horizons in the monotonous sandstones and shales, by which distortion can easily be recognized; just as the scalloped line of outcrop of the Medina sandstone reveals the folded structure of the Appalachians in Pennsylvania.

The conformity of the sandstones to the curved trap ridges is well known, but has never received its proper explanation. Percival described the trap ridges as "arranged according to a peculiar system, conformably with which the secondary rocks are themselves arranged" (10). "The trap ranges . . . . conform, in their arrangement, to that of the sandstone, and indeed have apparently exercised a controlling influence on the arrangement of the latter, thus indicating a cotemporary origin" (321; also 299, 408). He further says that both the general and particular direction of strike of the sandstone strata agrees with the trend of the trap ridges (430–432). Hitchcock noted the same arrangement for Massachusetts (*e*, 654; *h*, 17, and Pl. II.), and Cook mentions it for New Jersey (*c*, 29, 32).

An illustration of a flat fold producing a curve may be seen in the excellent example at Beckley, Conn. (D); it corresponds perfectly with the much larger curves shown by the Turner's Falls — Deerfield Range, by the great range from Belchertown, Mass. to Meriden, Conn., by many other smaller ranges in Connecticut so well shown on Percival's beautiful map, and by several similar curves in New Jersey. The most instructive region for the further study of this important point in the structure of the Triassic belts is without doubt the southeastern corner of the Connecticut sandstone area, about Durham and North Branford, — Percival's "volcanic focus" (311). I had hoped, but was unable, to reach it during the past summer.

All these folds are like flat oval dishes, tilted toward and faulted on the dip side of the general monoclinal; and as a necessary consequence of this, the trap sheets that are folded with the sandstones outcrop in crescentic ridges with the horns of the crescent pointing in the direction of general dip.* The fact of this position was first published by Percival in 1842 (311), but its cause was not then perceived. The folds are very numerous in Connecticut, but in Massachusetts and New Jersey they are fewer and larger: this would indicate that in the last two States there is the nearest approach to the simple monoclinal of the third theory of disturbance. An interesting exception to the rule occurs east of Saltonstall Lake, Conn.; it is P. 2 of E. I. of Percival's notation, and is described as abrupt on its eastern, convex side (325): this makes it seem very much like the eastern edge of a small sheet whose western outcrop is lettered P. 1 on Percival's map. Whether the small curves in southern Durham lettered P. 1 of E. III. are produced by folding, or result from the original form of intrusion or overflow, or are simply the effects of erosion, requires further observation to determine.†

In regard to the crescentic form of the trap ridges, H. D. Rogers considered it natural that the horns of the curves should point with the dip of the sandstone; for as a trap sheet made its way obliquely upward between the layers, the cover of the sandstone must have been cracked at the ends, allowing the trap to rise there and so turn the extremities of its outcrop with the dip of the bedded rocks (*e*). This was agreed to by Silliman, Jr. Whelpley thought the crescent ridges determined by the form of the fissures in the old rocks below the sandstones (64). Dana considered the curved ridges as marking curved fissures, characteristic of certain eruptions, and further added that the agreement in form of these ridges with more prominent features of the earth confirms "the view that ranges of mountains and islands correspond to ranges of fissures" (*a*, 391, 392); but later (*b*, *c*, 21) he essentially follows Rogers's explanation, and further says that the tilting was caused by the subsidence of the estuaries, and is "without evidence of folds" (*c*, 421). Wurtz considers that subsidence went on to a small amount during deposition, and was fastest along the axis of the belt. "Such slight inward inclination of the beds on both sides of the basin, explains the crescent form of the edges of the sheets of trap. The flow or propagation of the metamorphic agent being thus governed." (102.) Russell calls the curves "lines of least resistance," which were naturally and necessarily chosen by the eruptive trap (*c*, 241). Cook says, "The principal changes of dip appear to be, in some unexplained way, connected with the direction of the trap ridges, and are near them" (*c*, 29). All of these explanations, based on the intrusive origin of the trap, fail when the sheets are found to be overflows.

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* The imitation of this crescentic line of outcrop produced at a cross valley is mentioned under the observations at Beckley.

† It is greatly to be regretted that Percival had not the facilities for illustration afforded now by well-executed chromo-lithography. A map of the Connecticut valley drawn with as full an appreciation of topographic form as Percival must have possessed, and colored to show the different varieties of trap and sandstone, is needed to do justice to the remarkable features of this unique region. There is nothing like it known anywhere else in the world.

The value of the overflow sheets as marking horizons in the sandstone formation is thus very considerable, and will in time lead to closer measures of thickness than have yet been possible. The peculiar restriction of the localities of footprints in the Connecticut valley to the strata along the back of overflows is well shown by Hitchcock in the map in his Ichnology: it is evidently connected, as he suggests, with the appearance of volcanic islands and shallow waters in the old estuary.

6. SUMMARY.

The Triassic strata were deposited nearly horizontal in narrow estuaries not greatly exceeding their present area: some degrees of their dip may be the result of original oblique deposition, but this is insufficient to explain all of it. During their accumulation, extensive and repeated eruptions, very possibly from fissures, poured sheets of trap over their surface, to be buried under later deposits; and at the same time, or later, large and small trap sheets were forced laterally between the deep-lying strata. The period of deposition, and probably of eruption, was ended by an uplift that drained the sandstone areas, and tilted the included strata by small amounts from their original position. Some of the strips were bent into simple or faulted synclinals (Nova Scotia, Richmond coal field); one was thrown into gentle waves (Prince Edward Island); the others received their peculiar monoclinal tilting. Why the general monoclinal structure was produced cannot now be clearly explained; but by means of the overflow trap sheets, which serve perfectly as identifiable horizons in the monotonous sandstones and shales, it can be shown that there are distinct folds in these monoclinals, thus explaining the crescentic form of the trap ridges. The folds are of small pattern in Southern Connecticut; on a much larger scale in Nova Scotia, Massachusetts, and New Jersey. Faults also occur: some of small throw are directly visible; some of much greater displacement are properly inferred from the repetition of similar series of strata; and many more probably exist hidden under drift and soil: thus the necessity is avoided of supposing a great thickness for the formation. The erosion of the sedimentary and igneous strata into their present form was probably accomplished in great part during a time of greater land elevation than the present; but it presents nothing abnormal.

The physical features of the Triassic belts that seem most worthy of further observation are, first, a closer identification than has yet been made of the source of the conglomerates that not unfrequently occur along either margin of the belts, thus allowing or excluding the ideas of original oblique bedding and of anticlinal remnants; second, the determination of the overflow or intrusive origin of the many undetermined trap ridges; third, the further proof that the curvature of these ridges implies a folding of the strata; fourth, the closer identification of the surmised but undiscovered faults.

CAMBRIDGE, January 8, 1883.

EXPLANATION OF PLATES.

THIS article is accompanied by three plates, numbered IX., X., and XI., with fifty-two figures, numbered consecutively.

Plate IX., figs. 1–31, gives a general graphic review of the opinions held concerning the relations of the trap and sandstones from 1818 to 1880. The references to the originals of the drawings are given on pp. 280, 281.

Plates X. and XI. Sketch-maps serving as guides to the localities of the observations above described, and figures representing some of the results obtained. Page numbers refer to explanations in the text.

Fig. 32. Turner's Falls, Mass. Fig. 33. Section of trap ridges (p. 259). Fig. 34. Fragments of trap in overlying sandstone (pp. 260, 300).

Fig. 35. About Mount Tom, Mass. (p. 261). Fig. 36. Section of Mount Tom and posterior ridge (p. 261). Fig. 37. Generalized section of contact, Delany's Quarry (p. 262).

Fig. 38. Railroad cut in posterior trap ridge, West Springfield, Mass. (p. 263).

Fig. 39. Map and section of curved trap ridge at Beckley Station, Middletown Branch Railroad, Conn. (pp. 264, 265, 306).

Fig. 40. The Hanging Hills from Meriden (p. 265). Fig. 41. The same in section (p. 266). Fig. 42. Map of the same (p. 266). Fig. 43. The same with Lamentation Mountain, as seen from Wallingford, Conn., showing place and throw of probable fault (pp. 266, 305).

Fig. 44. Dikes near East Haven, Conn. (pp. 268, 292).

Fig. 45. Side of ragged dike, Wallingford, Conn. (p. 266).

Fig. 46. Base of Palisade trap cutting sandstone, Weehawken, N. J. (p. 270).

Fig. 47. Garret Rock, First Mountain, Paterson, N. J. (pp. 273,304). Fig. 48. Gorge at Passaic Falls, Paterson (pp. 272, 300).

Fig. 49. Peculiar conglomerate overlying First Mountain trap, Feltville, N. J. (p. 275). Fig. 50. *a*, *b*, the same, natural size (p. 275).

Fig. 51. Intruded trap sheets, Martin's Dock, below New Brunswick, N. J. (pp. 276, 295).

Fig. 52. Intruded trap sheets, near Point Pleasant Station, Belvidere Railroad, N. J. (pp. 277, 295).

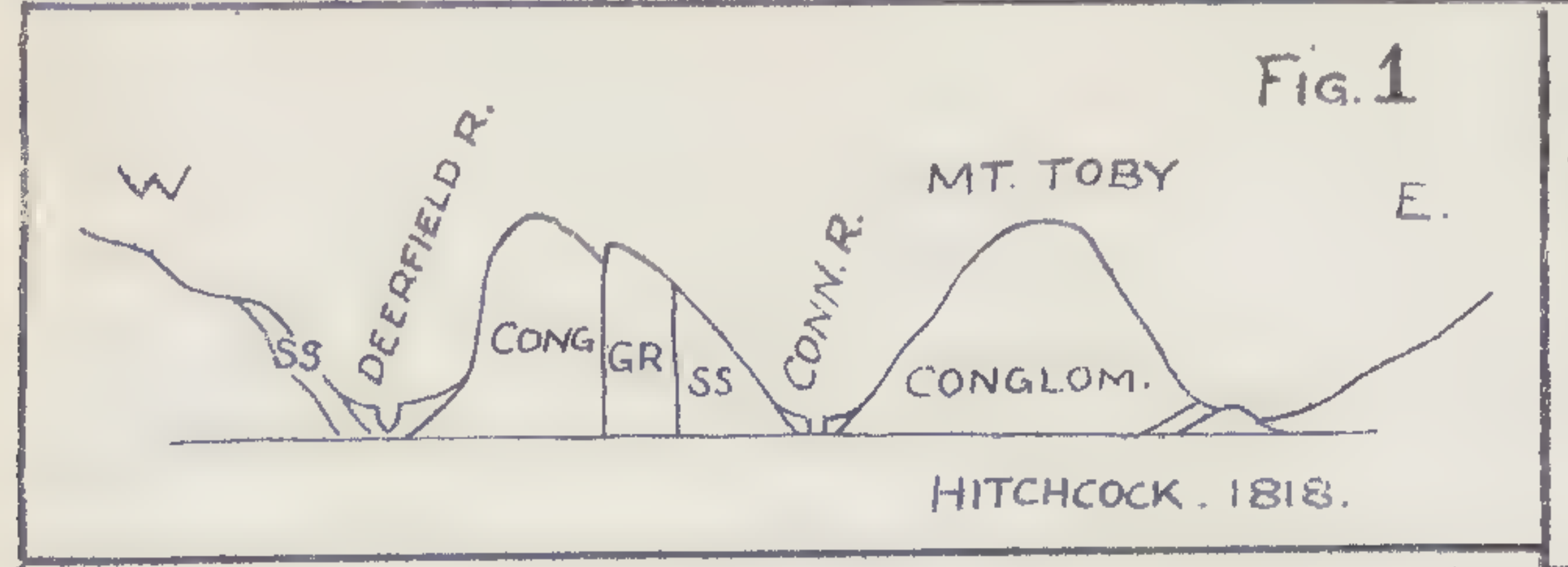
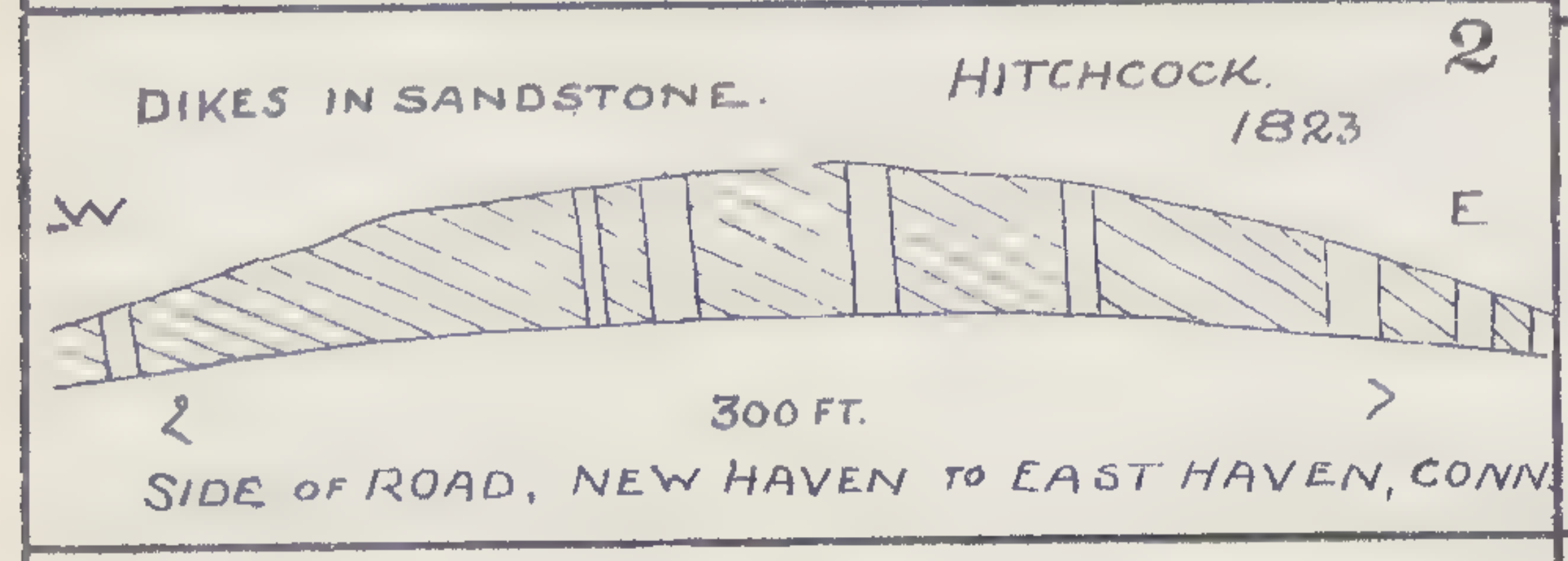
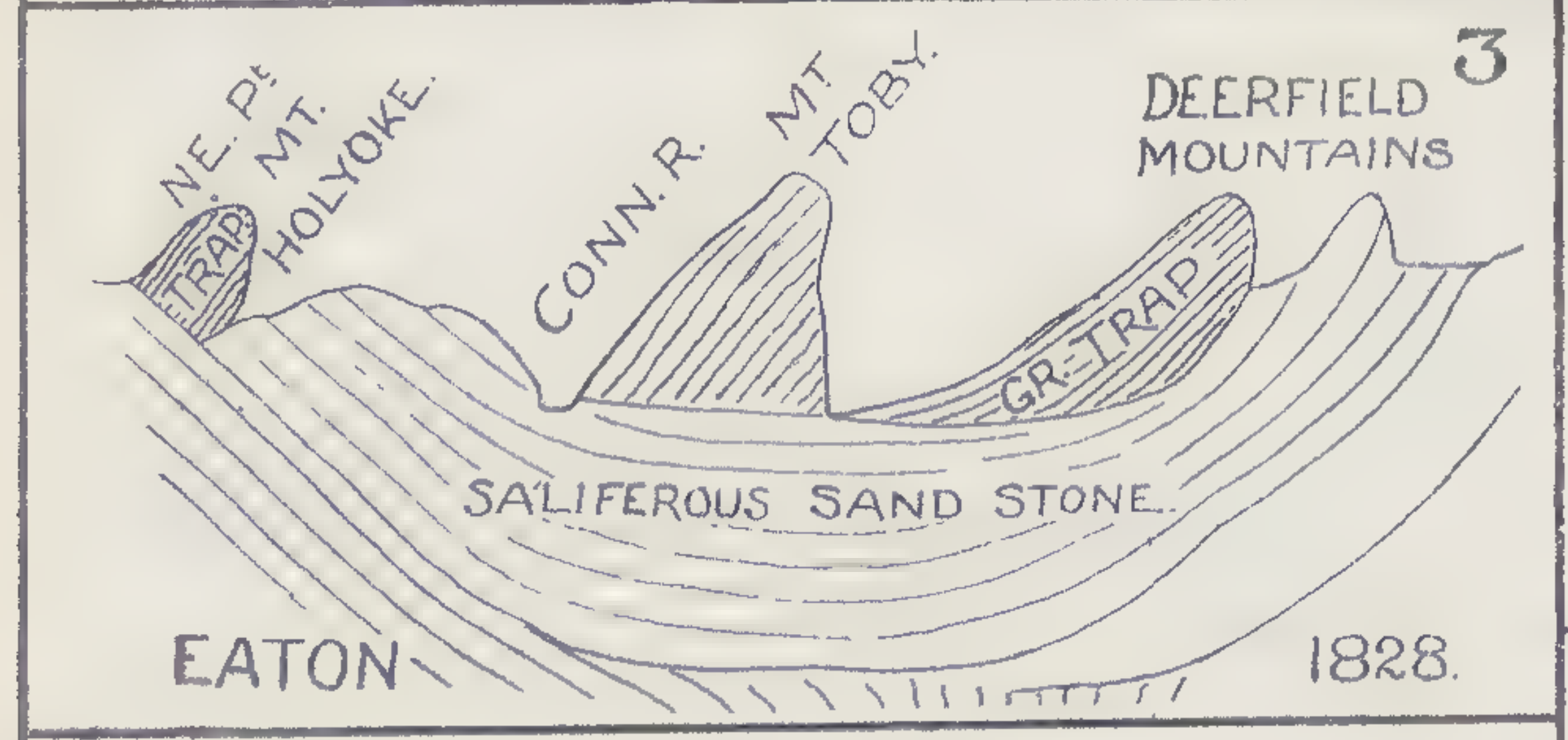
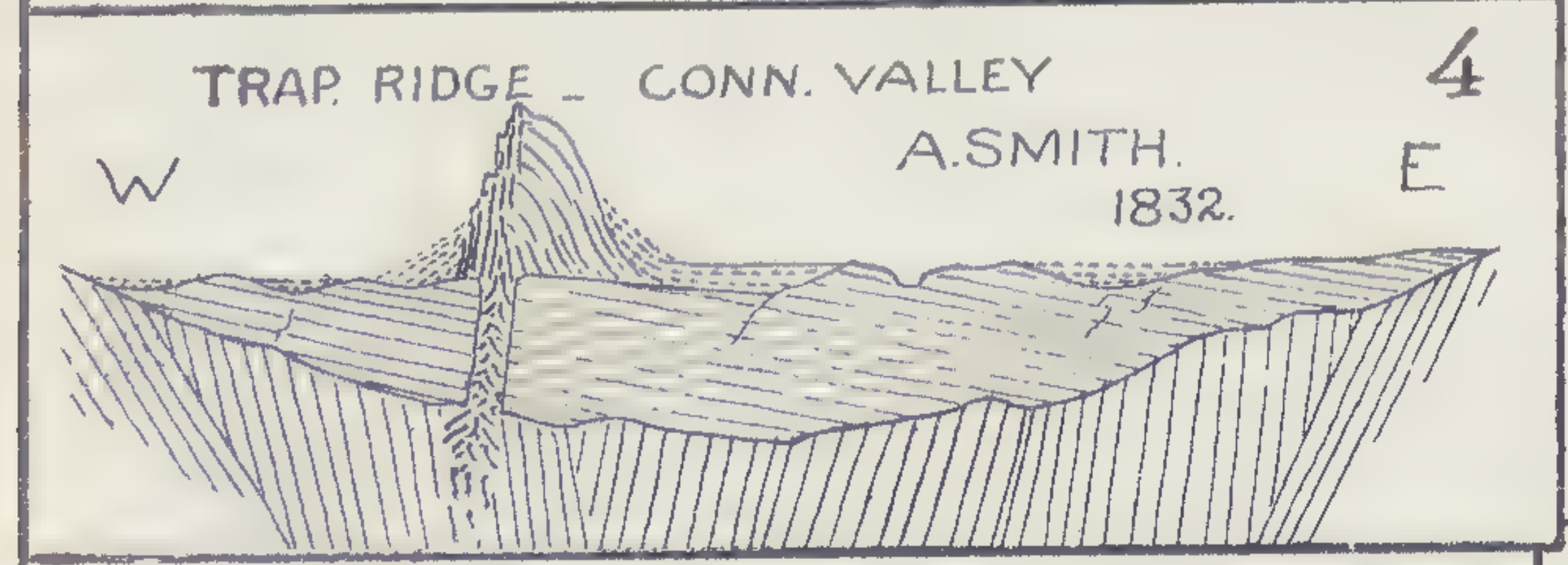
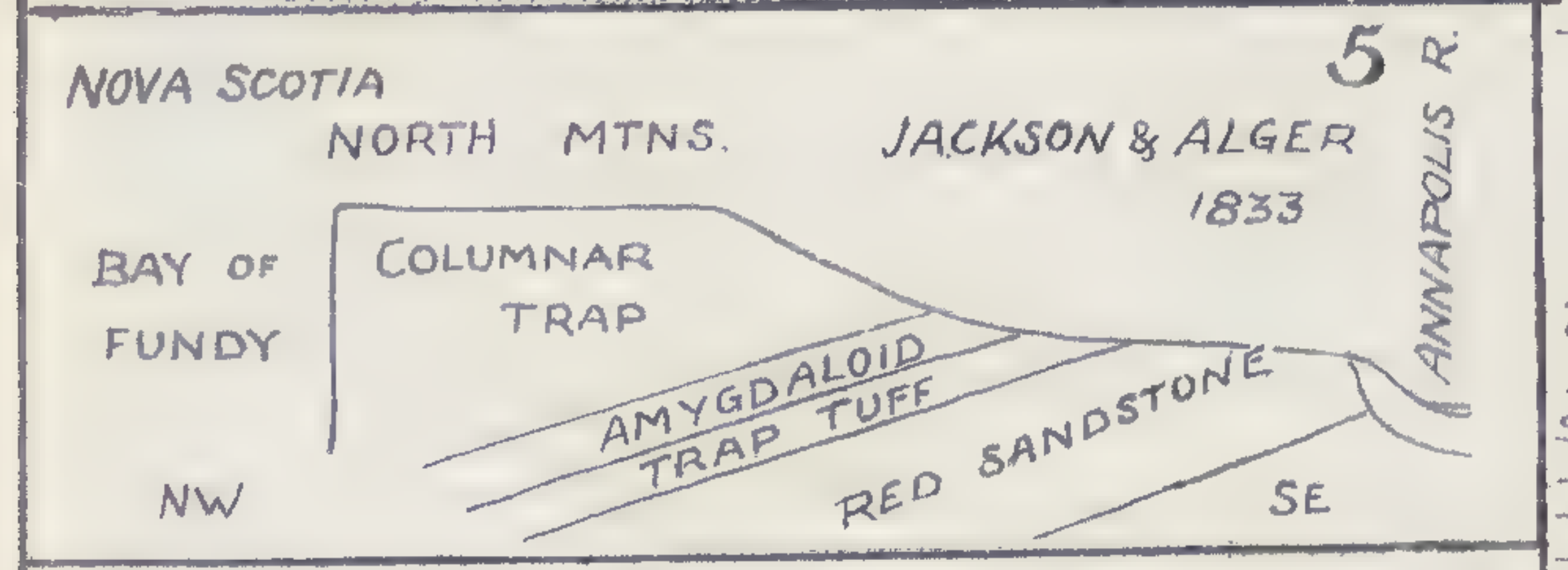


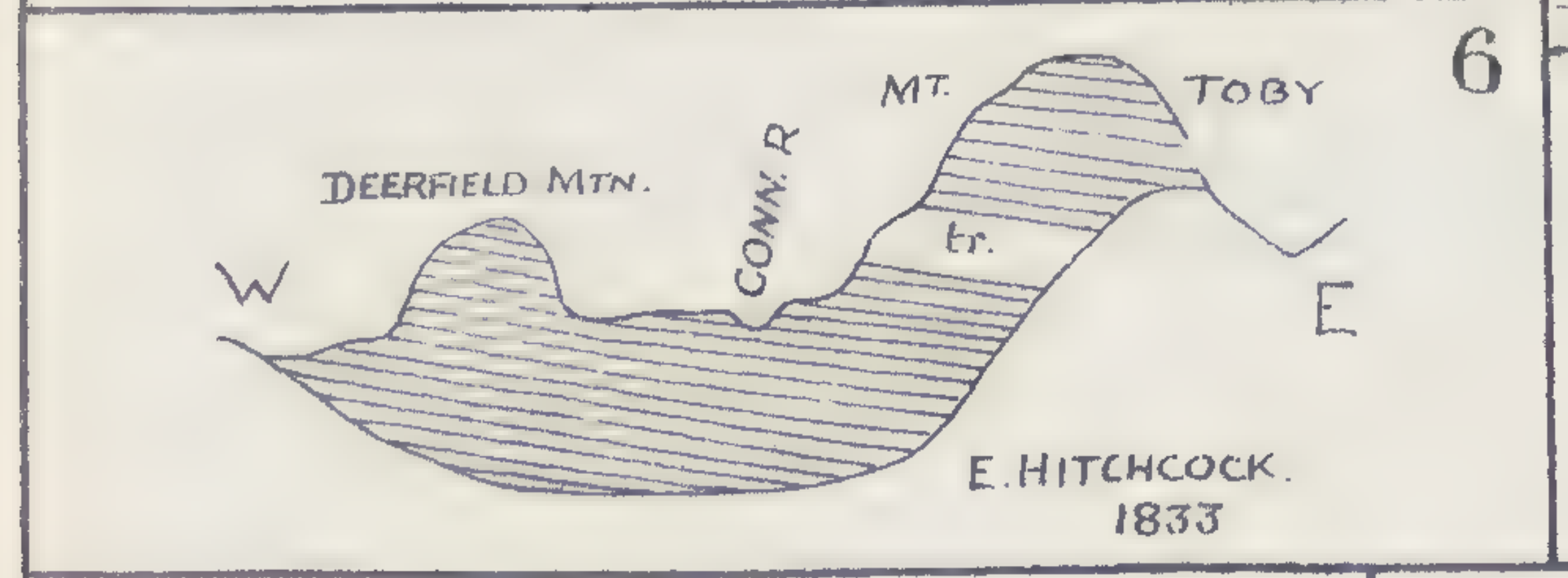
FIG. 1
W
DEERFIELD R.
MT. TOBY
E.
SS
CONG
GR
SS
CONN. R.
CONGLOM.
HITCHCOCK. 1818.

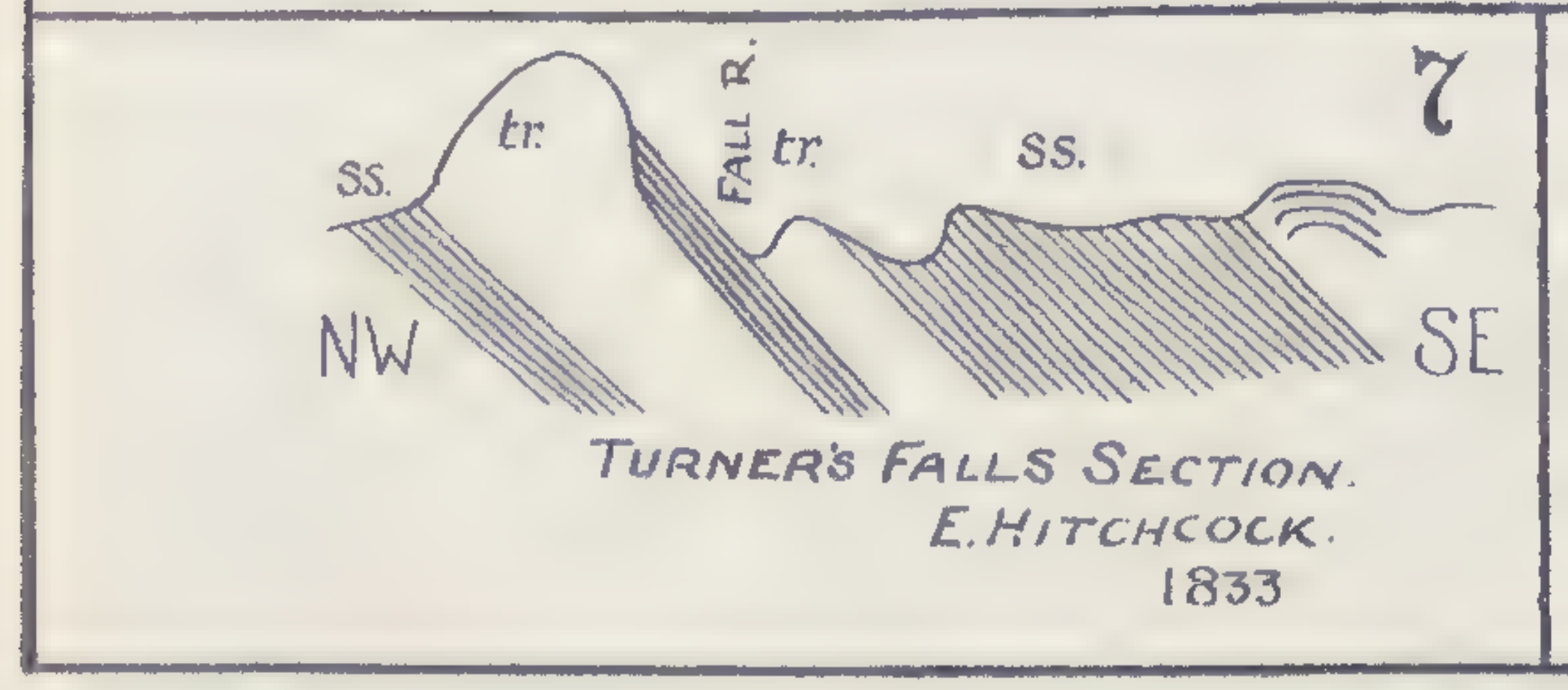

2
DIKES IN SANDSTONE.
HITCHCOCK. 1823
W
E
300 FT.
SIDE OF ROAD, NEW HAVEN TO EAST HAVEN, CONN.

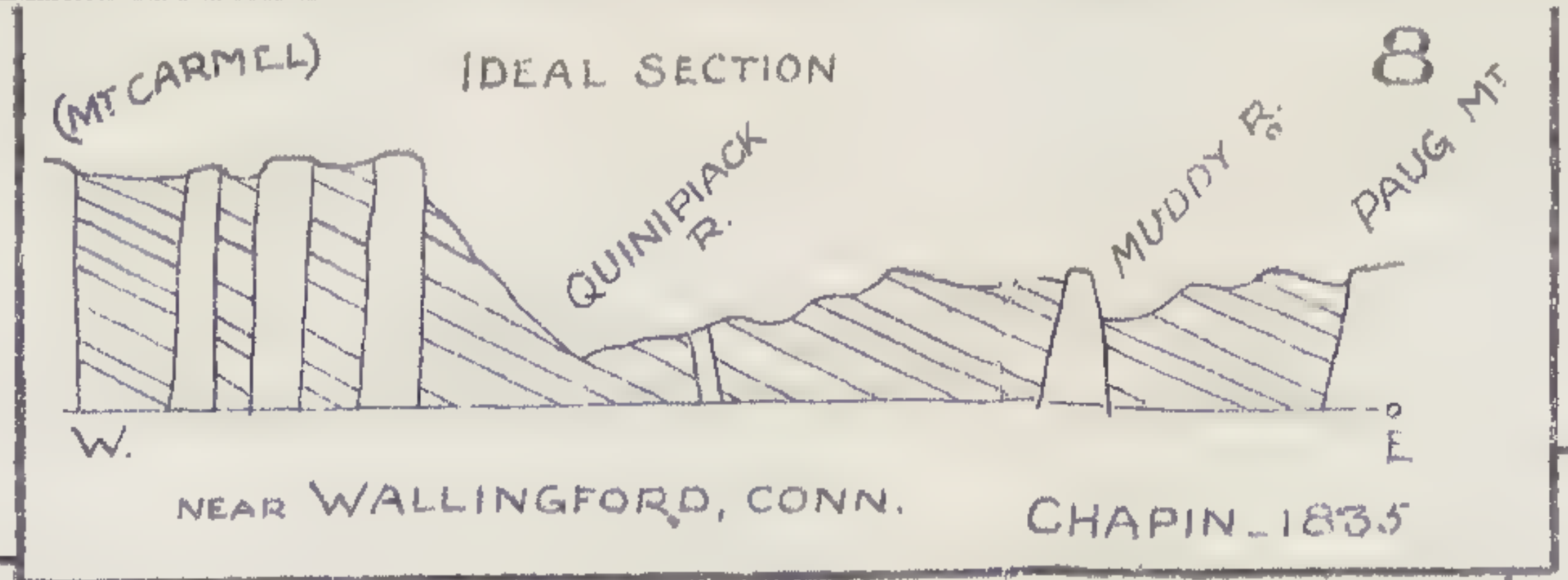

3
NE. PT MT. HOLYOKE
TRAP
CONN. R.
MT TOBY
DEERFIELD MOUNTAINS
GR. TRAP
SALIFEROUS SAND STONE.
EATON
1828.

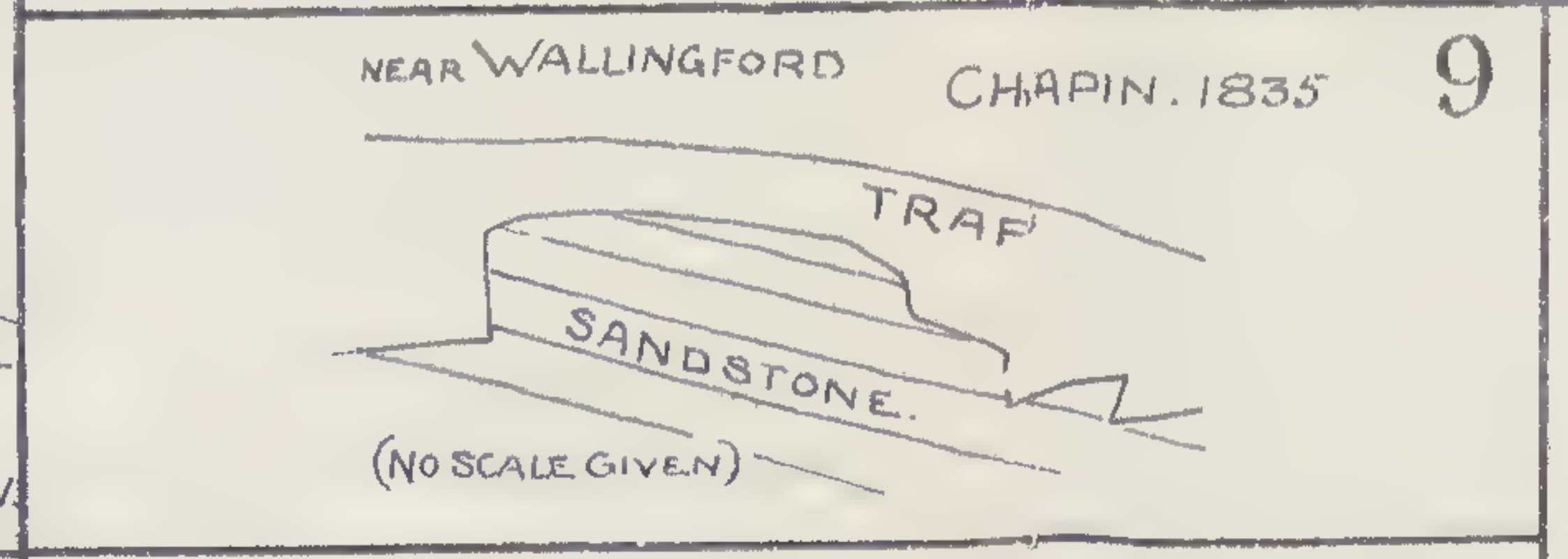

4
TRAP RIDGE - CONN. VALLEY
A. SMITH. 1832.
W
E

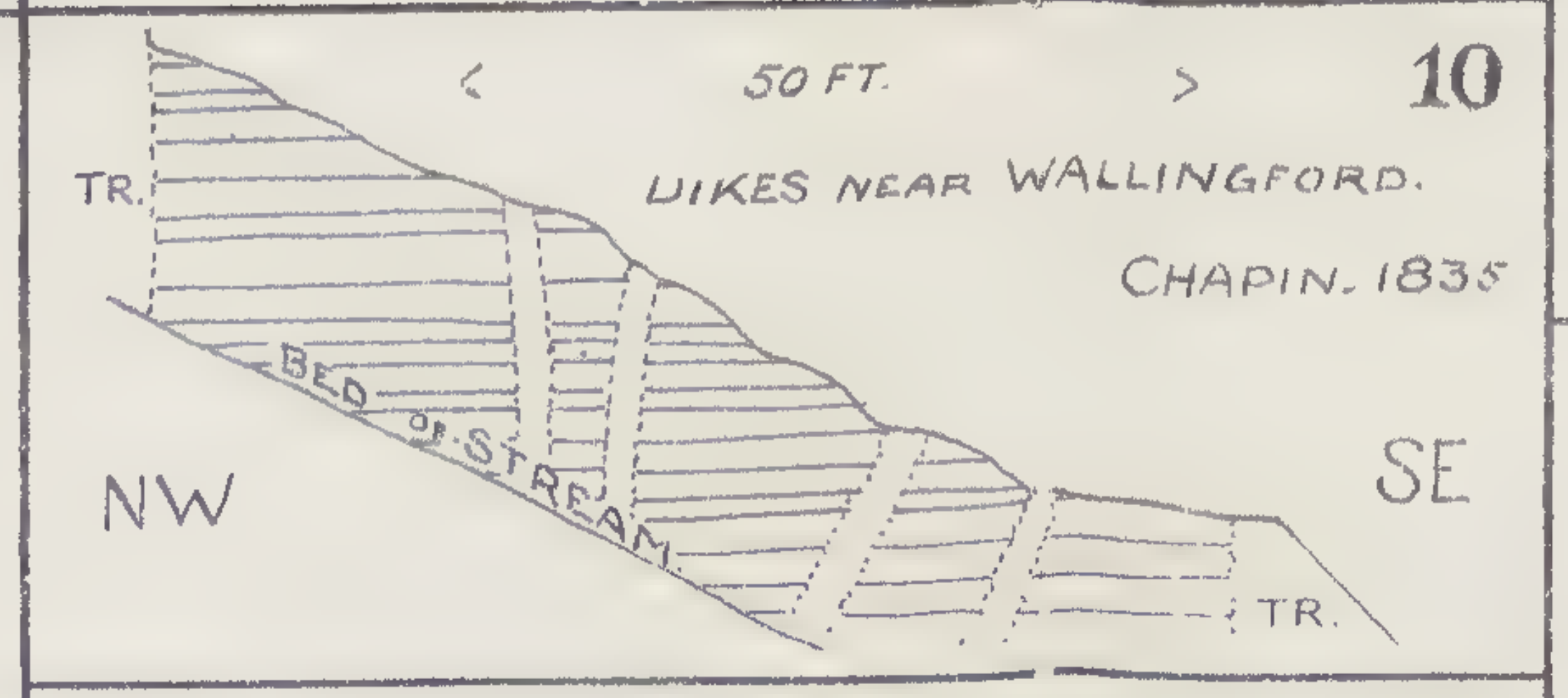

5
NOVA SCOTIA
NORTH MTNS.
JACKSON & ALGER 1833
ANNAPOLIS R.
BAY OF FUNDY
COLUMNAR TRAP
AMYGDALOID
TRAP TUFF
RED SANDSTONE
NW
SE

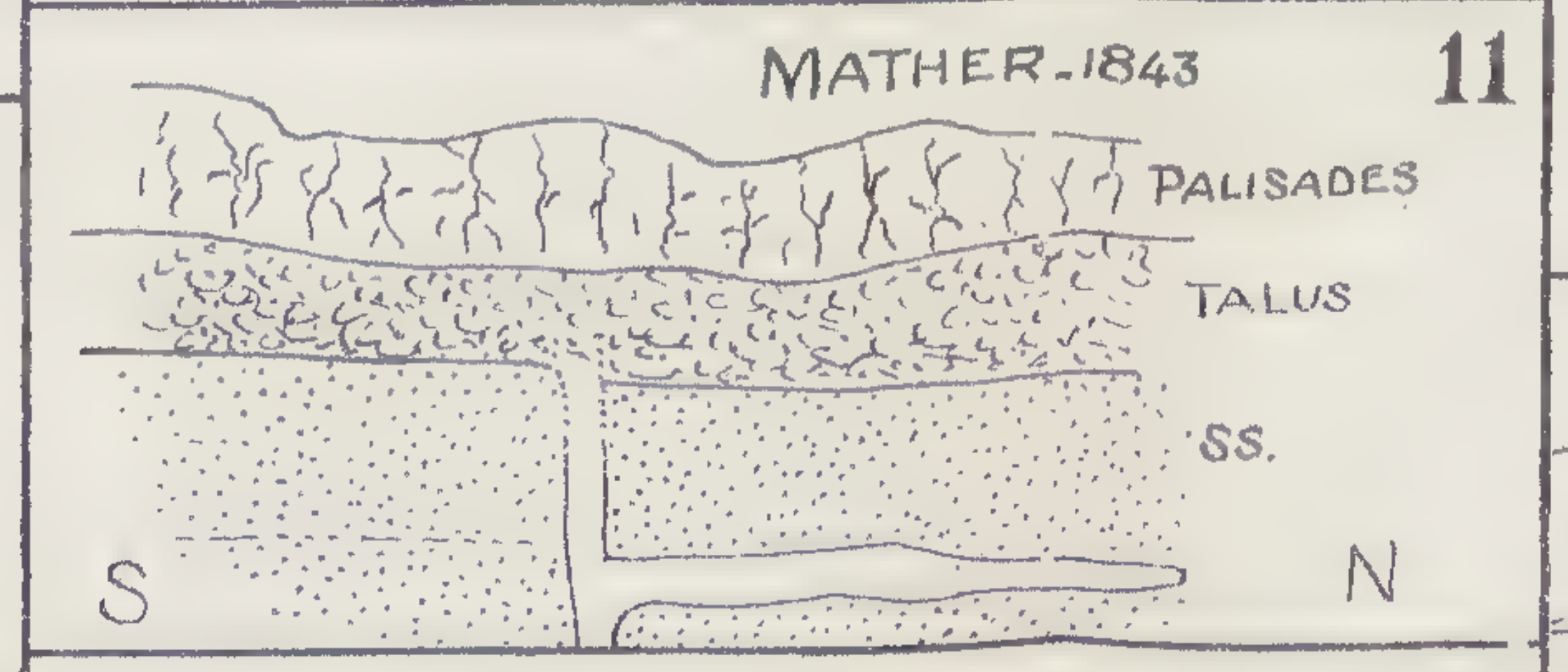

6
DEERFIELD MTN.
CONN. R
MT. TOBY
tr.
W
E
E. HITCHCOCK 1833

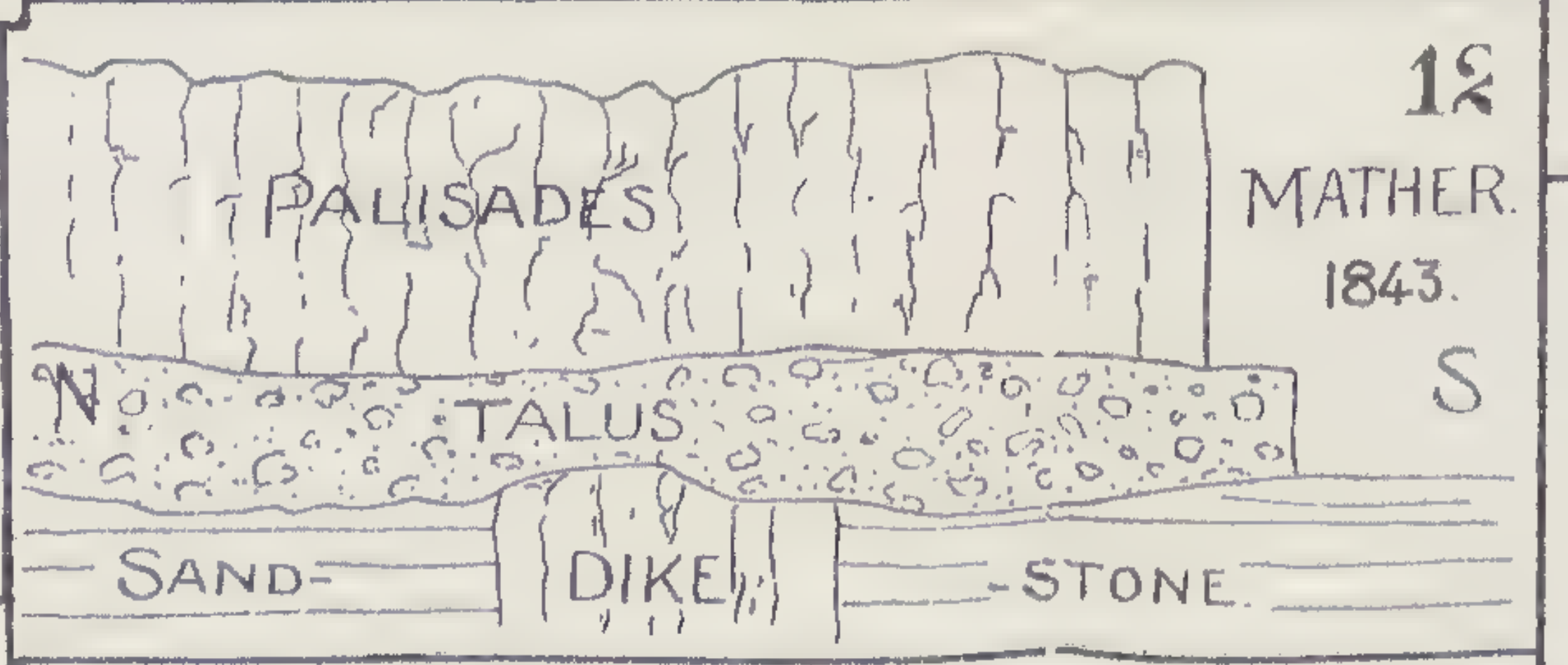

7
SS.
tr.
FALL R.
tr
SS.
NW
SE
TURNER'S FALLS SECTION.
E. HITCHCOCK.
1833

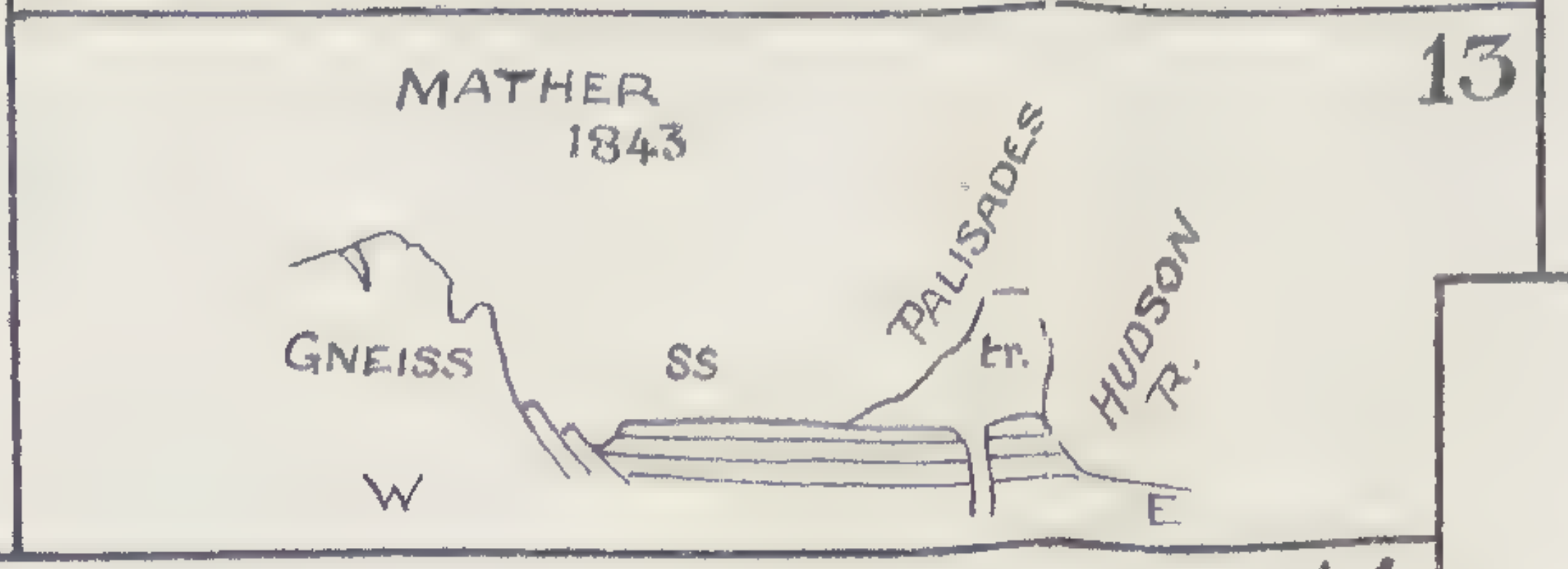

8
(MT CARMEL)
IDEAL SECTION
QUINIPIACK R.
MUDDY R.
PAUG. MT
W.
E
NEAR WALLINGFORD, CONN.
CHAPIN 1835

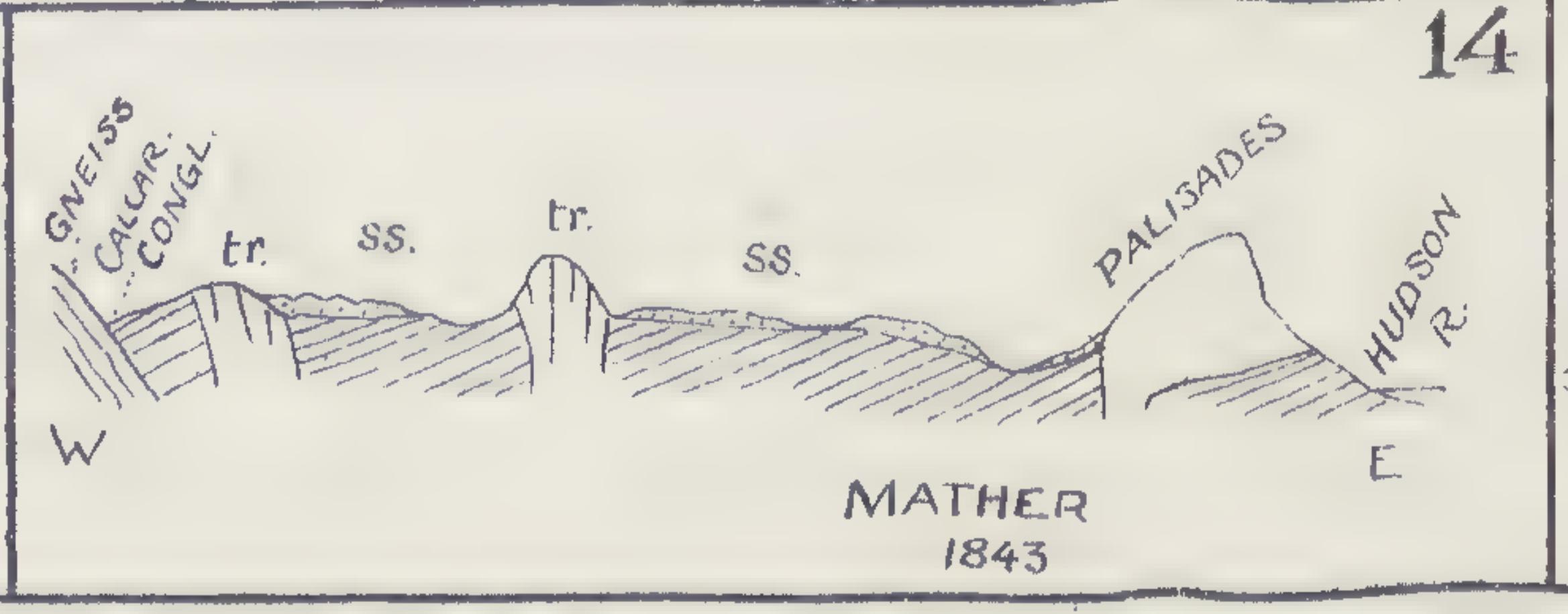

9
NEAR WALLINGFORD
CHAPIN. 1835
TRAP
SANDSTONE.
(NO SCALE GIVEN)

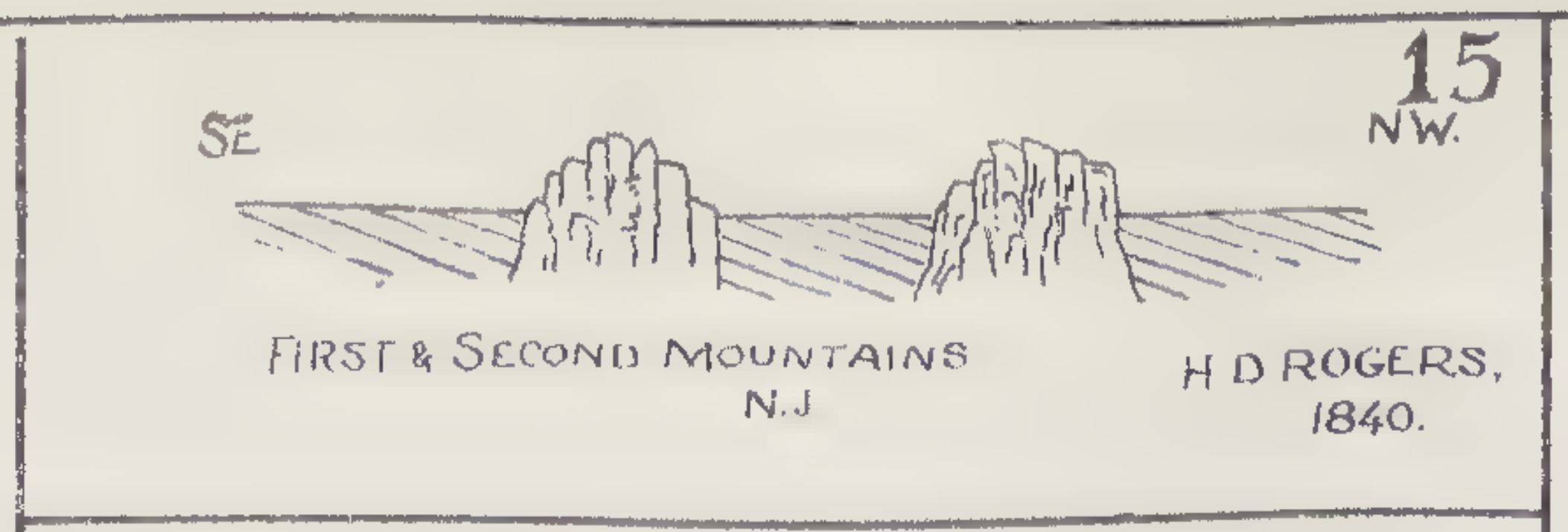

10
50 FT.
TR.
DIKES NEAR WALLINGFORD.
CHAPIN. 1835
BED OF STREAM
NW
SE
TR.

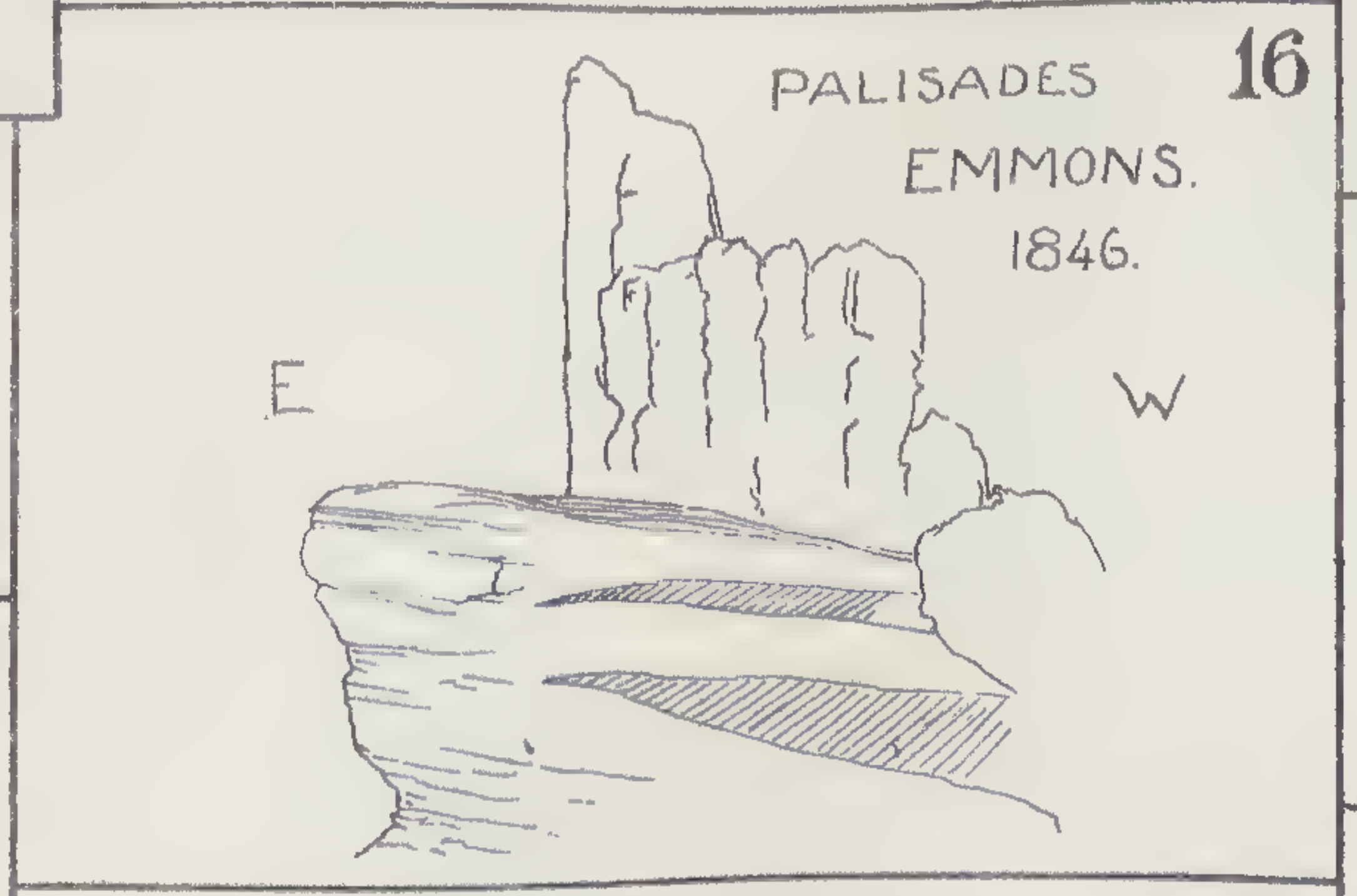

11
MATHER 1843
PALISADES
TALUS
SS.
S
N

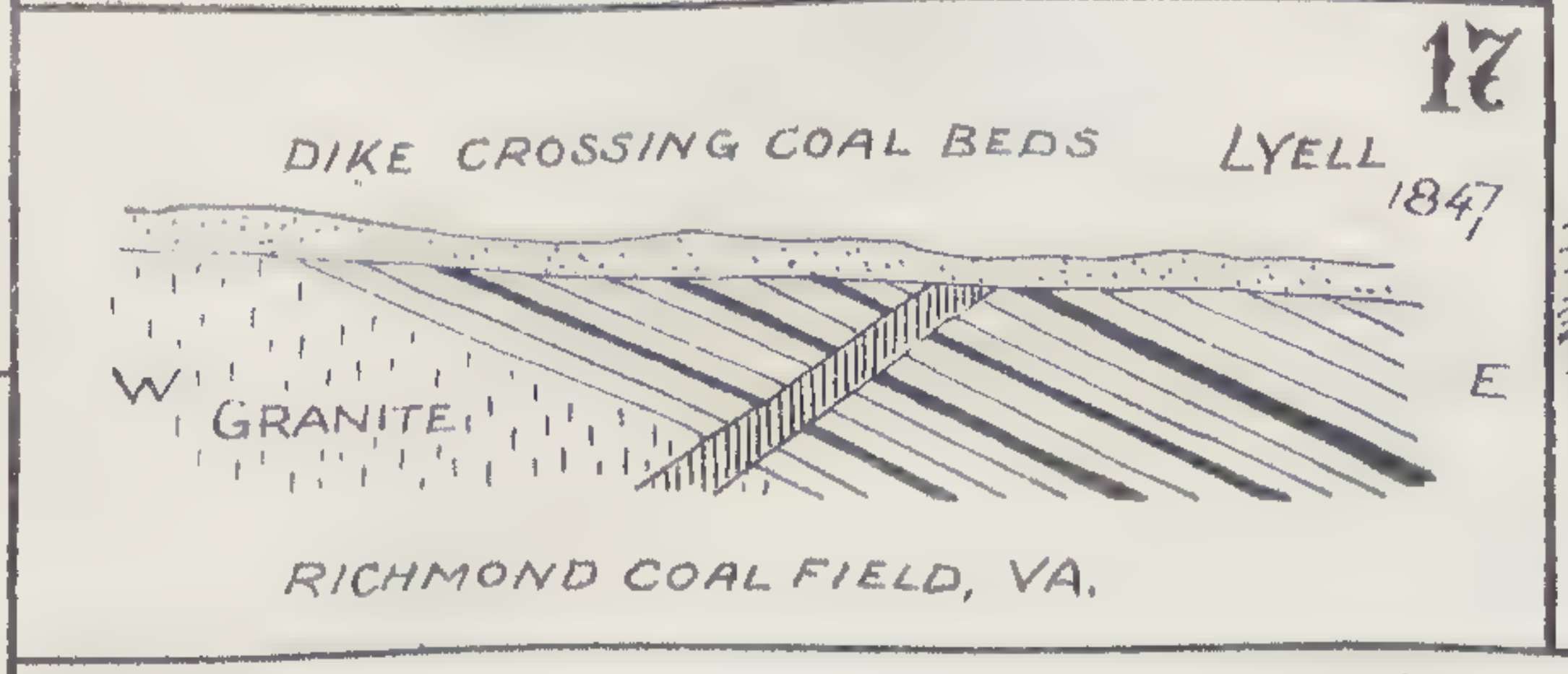

12
PALISADES
MATHER. 1843.
N
S
TALUS
SAND-
DIKE
-STONE.

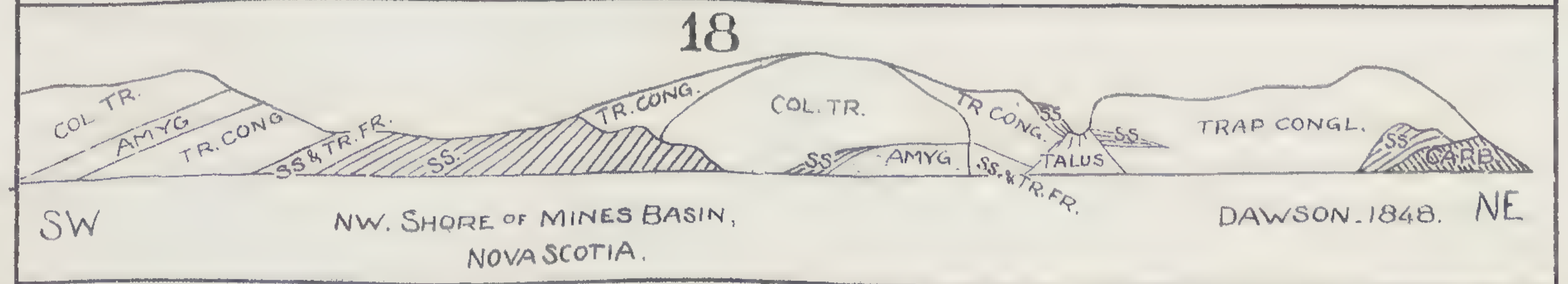

13
MATHER 1843
GNEISS
SS
PALISADES
tr.
HUDSON R.
W
E

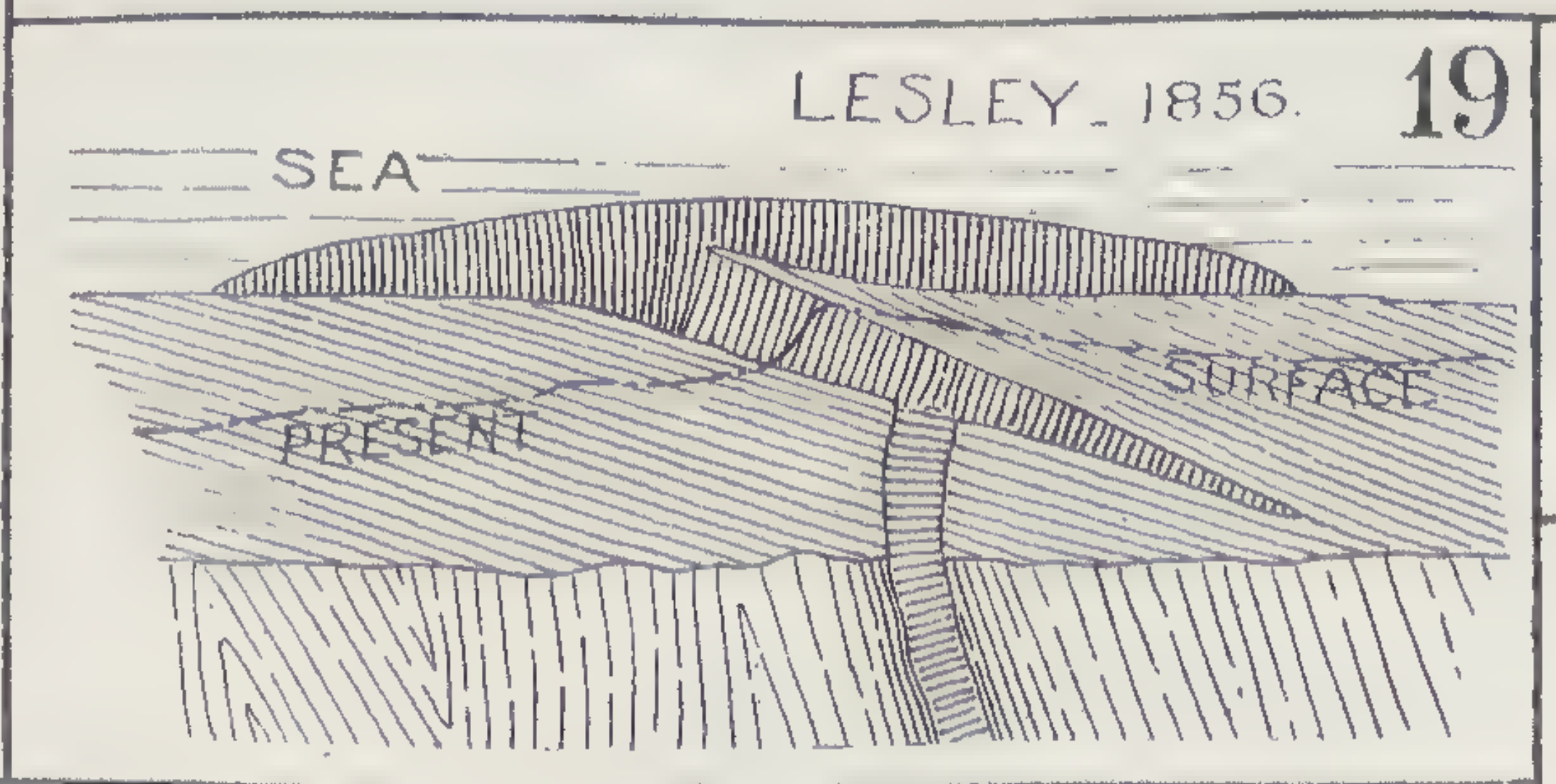

14
GNEISS
CALCAR. CONGL.
tr.
SS.
tr.
SS.
PALISADES
HUDSON R.
W
E
MATHER 1843

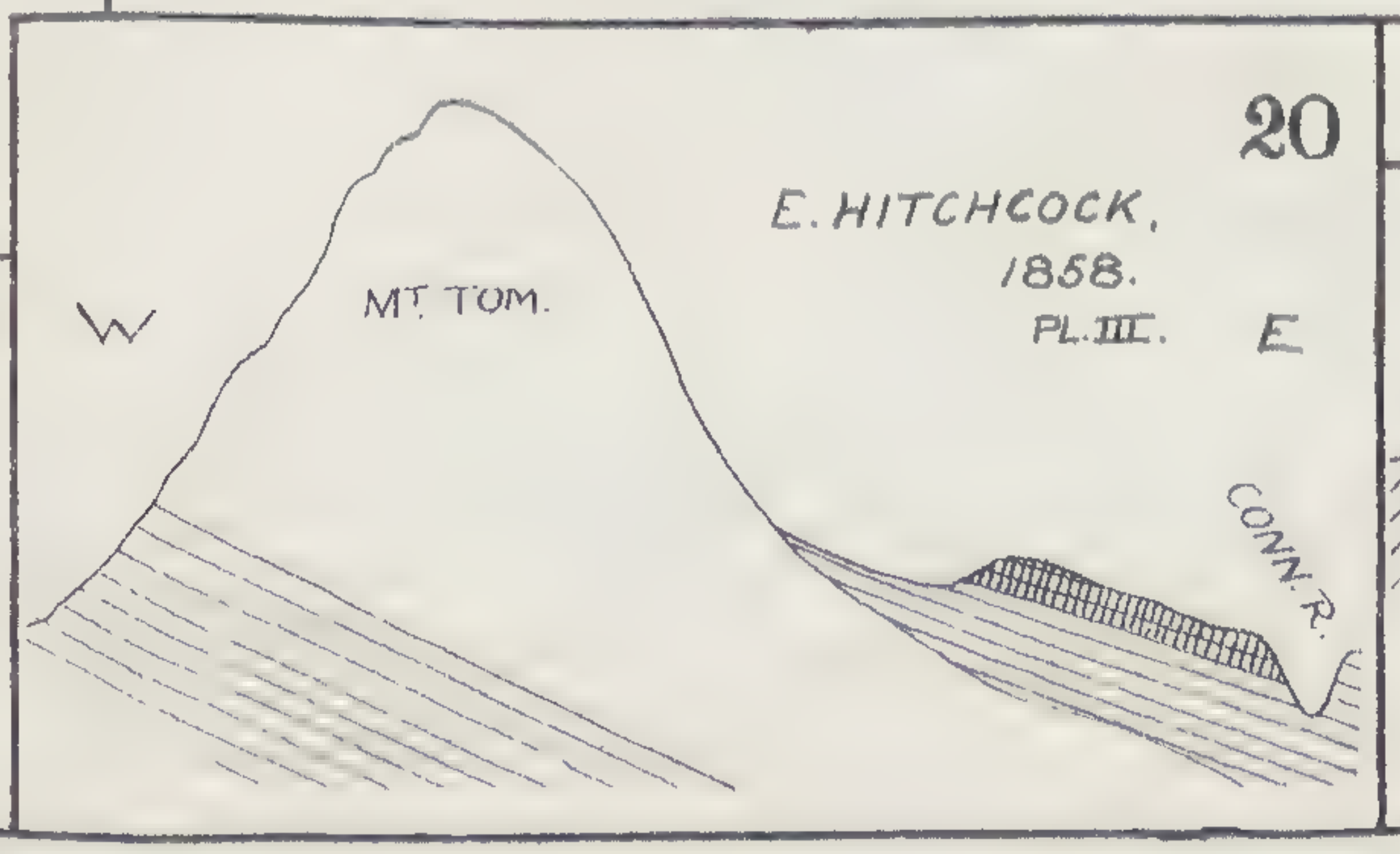

15
SE
NW.
FIRST & SECOND MOUNTAINS N.J
H.D. ROGERS. 1840.

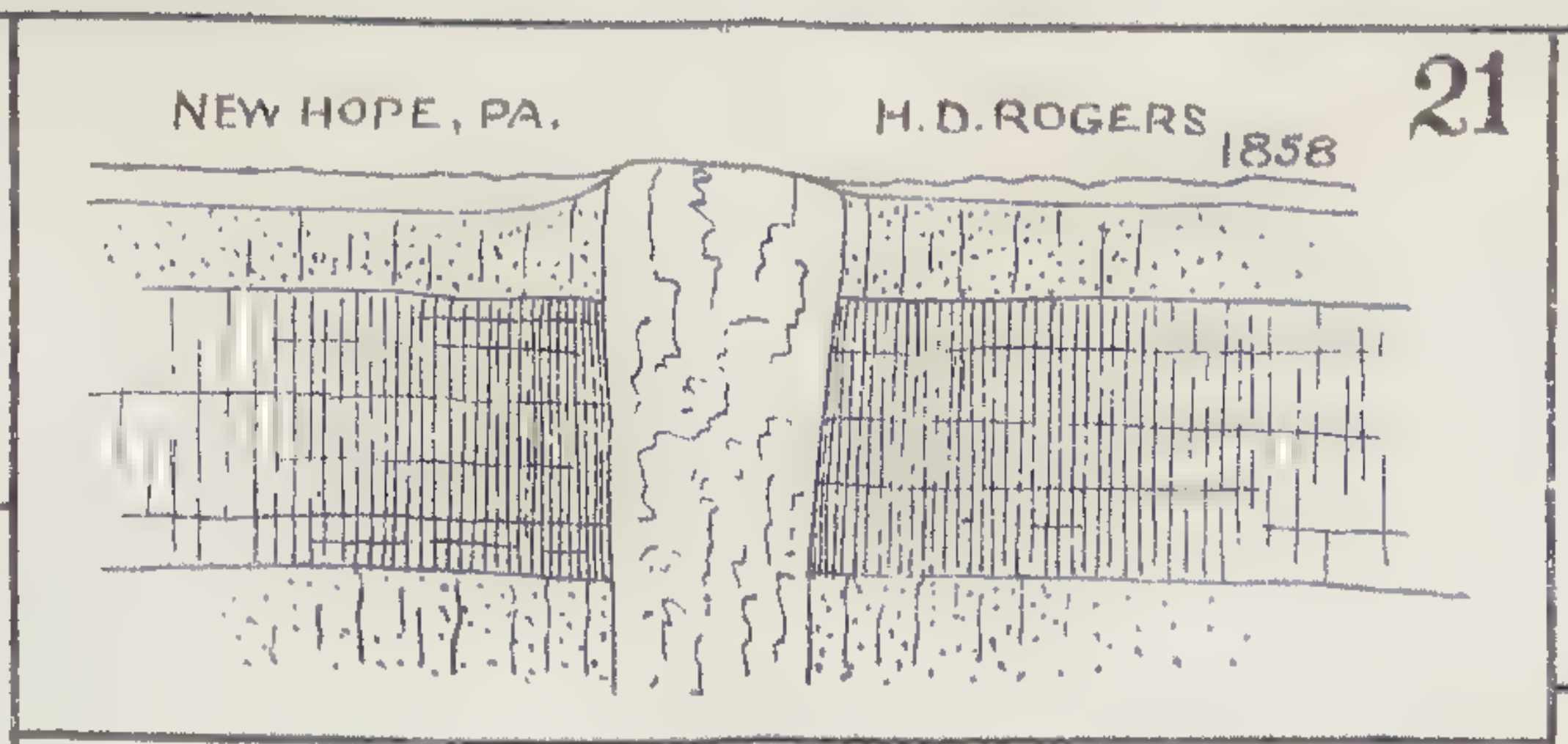

16
PALISADES
EMMONS. 1846.
E
W

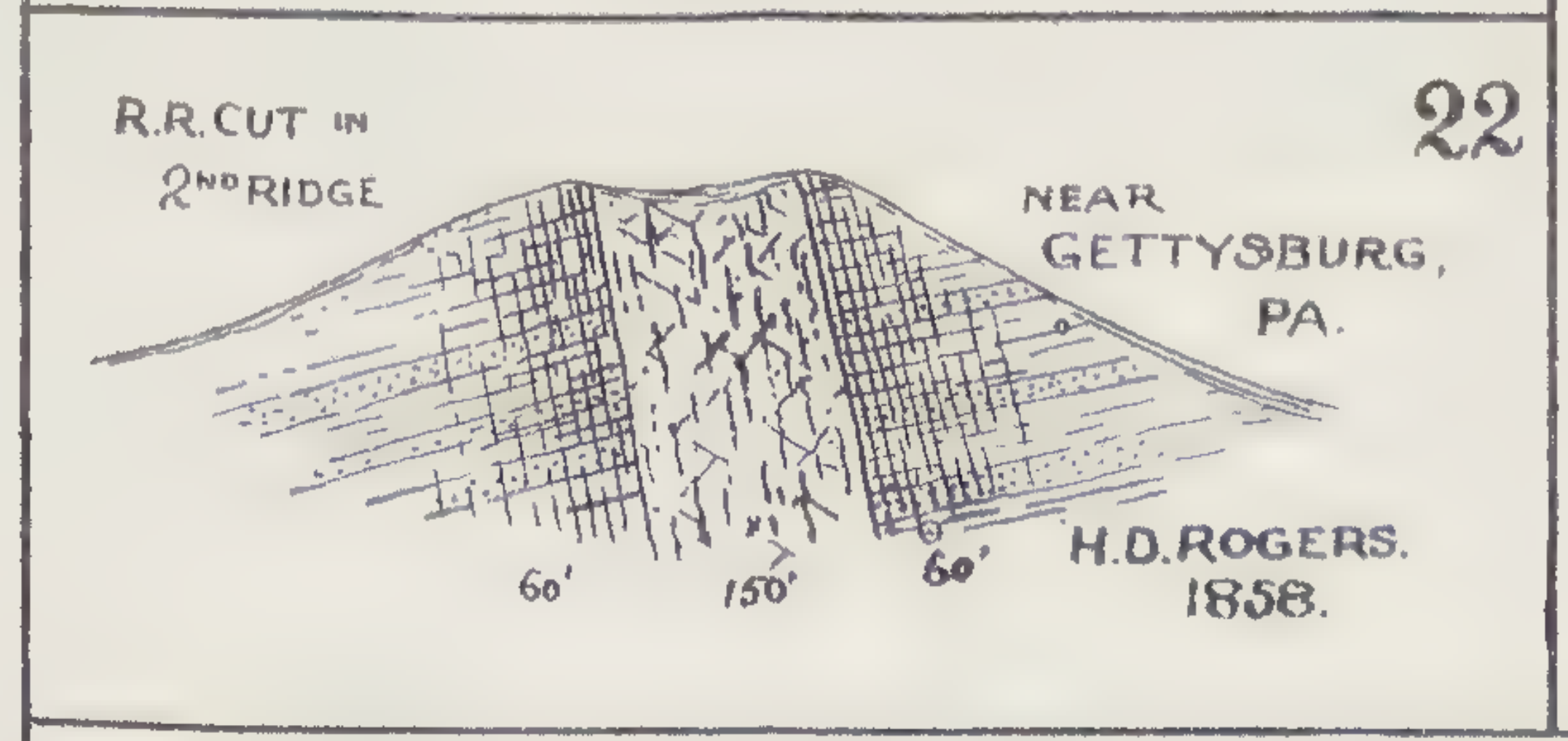

17
DIKE CROSSING COAL BEDS
LYELL 1847
W
GRANITE
E
RICHMOND COAL FIELD, VA.

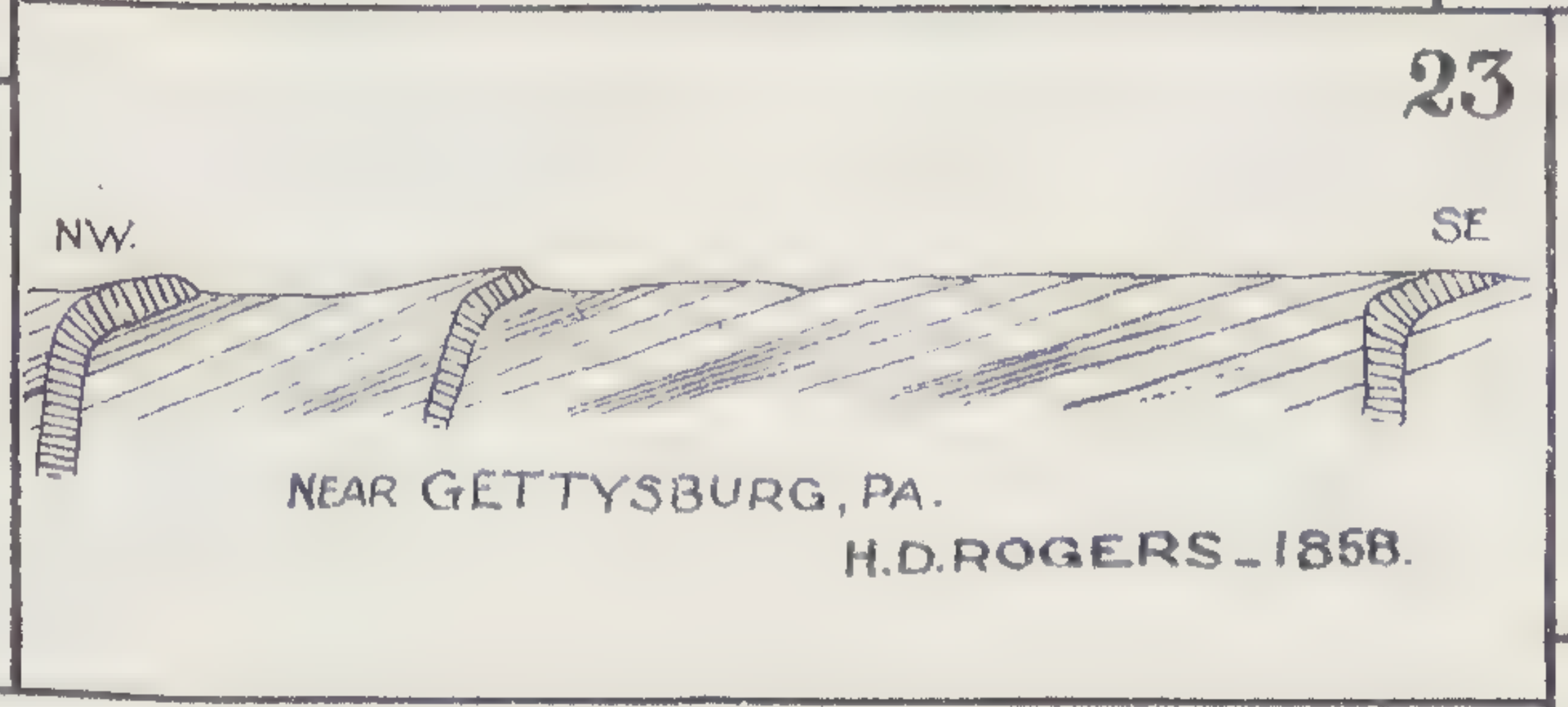

18
COL. TR.
AMYG
TR. CONG
SS & TR. FR.
SS.
TR. CONG.
COL. TR.
SS
AMYG
SS & TR. FR.
TR CONG.
SS
TALUS
SS.
TRAP CONGL.
SS
CARB
SW
NW. SHORE OF MINES BASIN, NOVA SCOTIA.
DAWSON. 1848.
NE

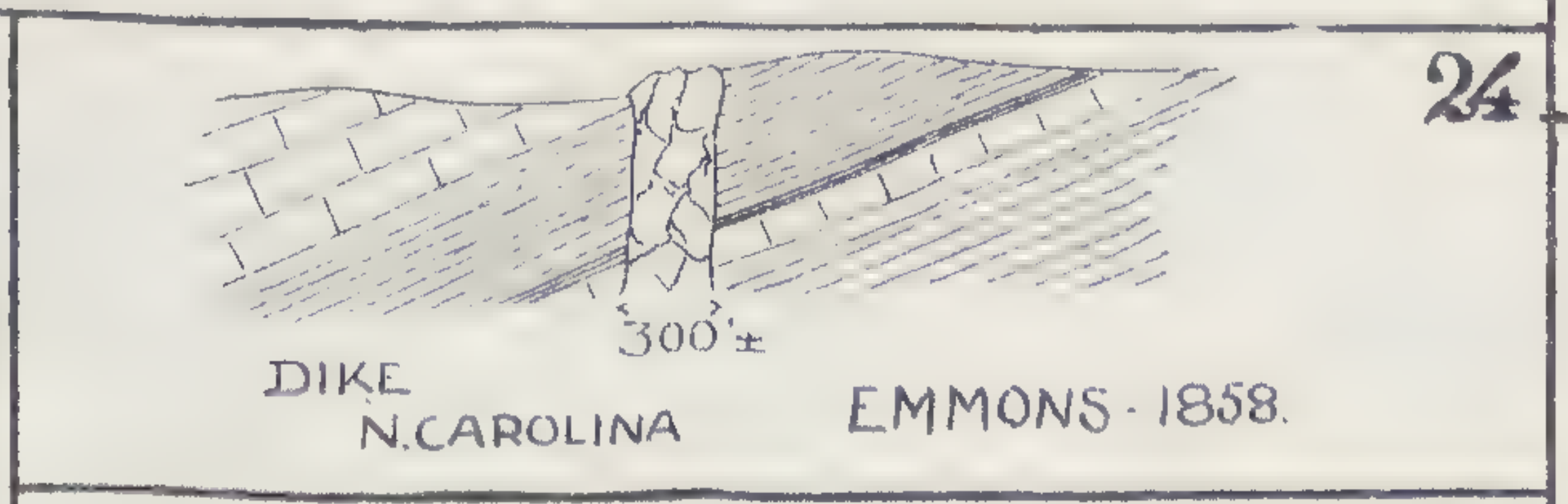

19
LESLEY 1856.
SEA
PRESENT
SURFACE

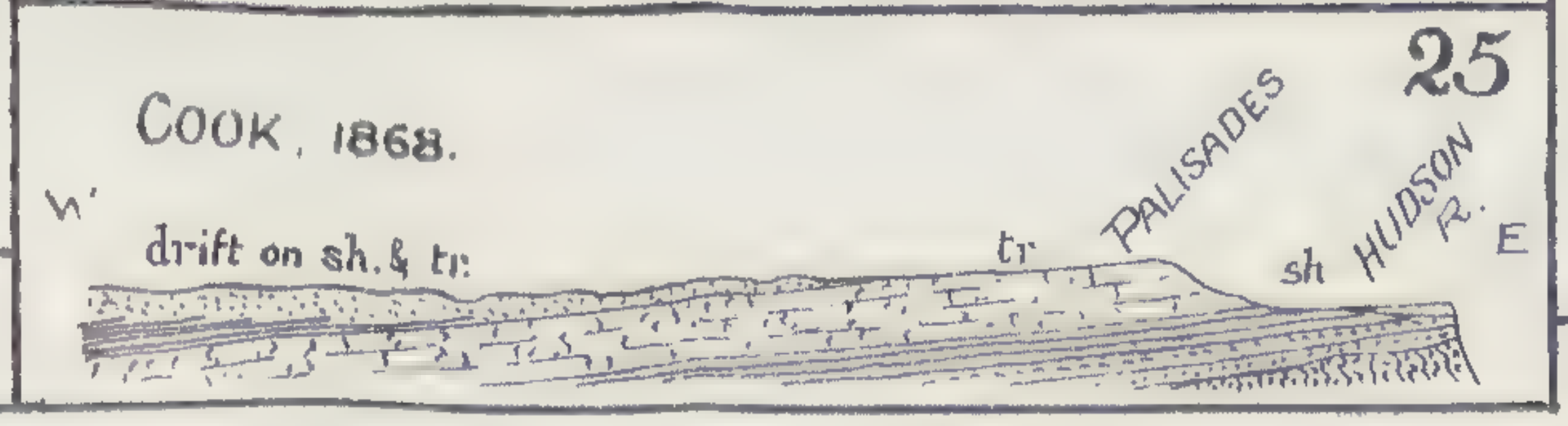

20
W
MT. TOM.
E. HITCHCOCK, 1858. PL. III.
E
CONN. R.

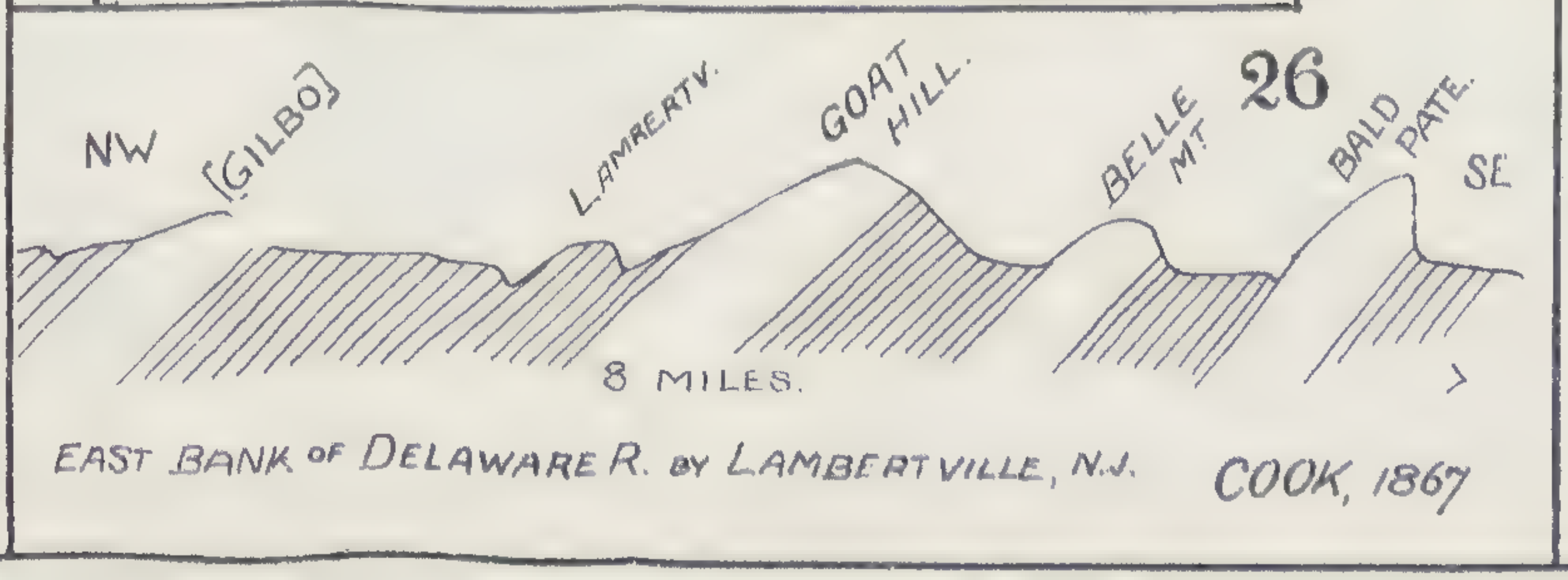

21
NEW HOPE, PA.
H.D. ROGERS 1858

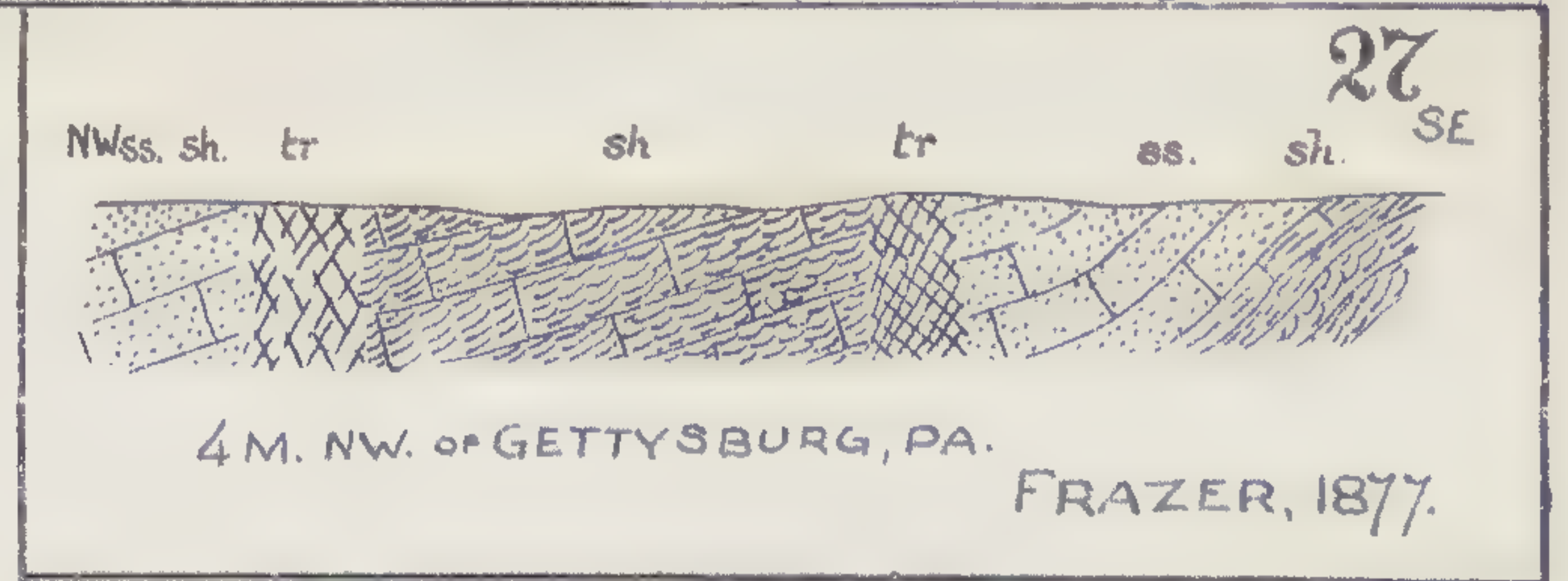

22
R.R. CUT IN 2ND RIDGE
NEAR GETTYSBURG, PA.
60'
150'
60'
H.D. ROGERS. 1858.

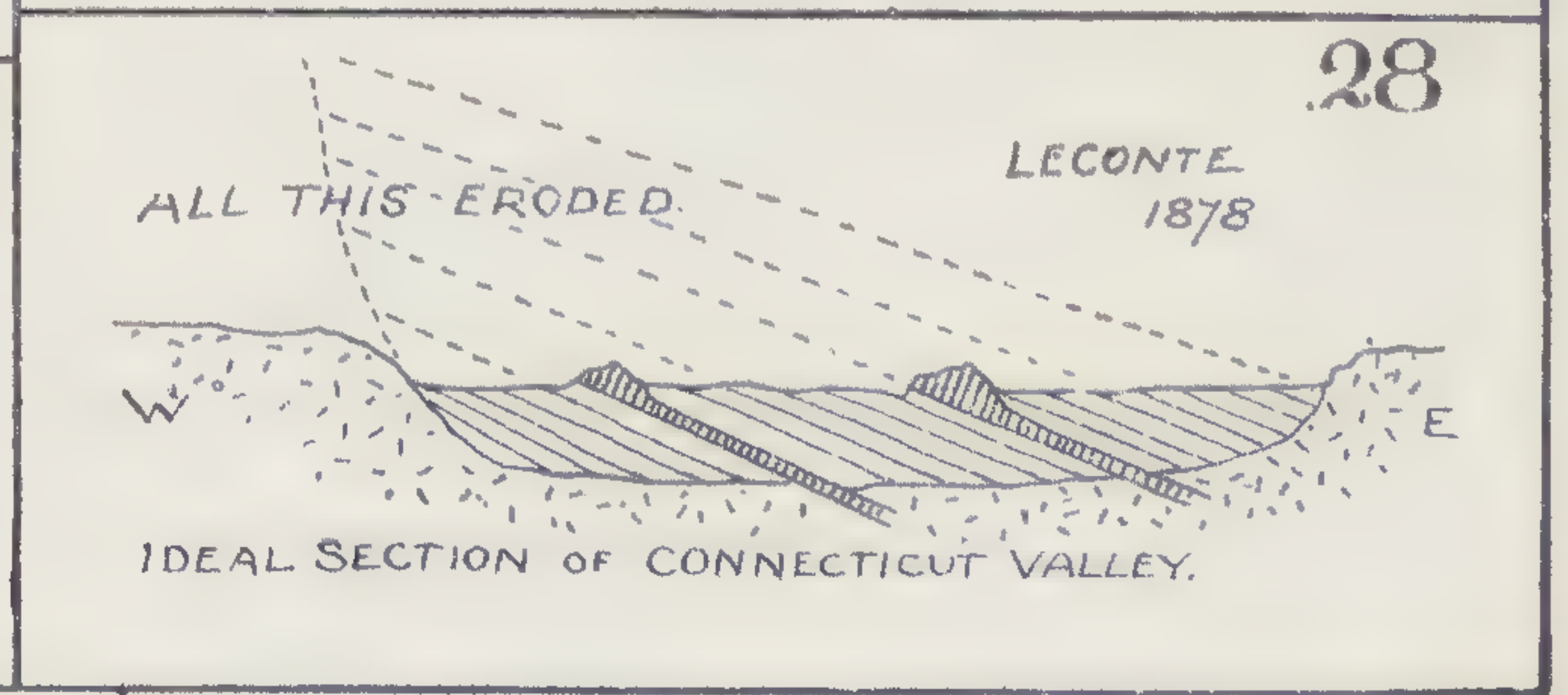

23
NW.
SE
NEAR GETTYSBURG, PA.
H.D. ROGERS 1858.

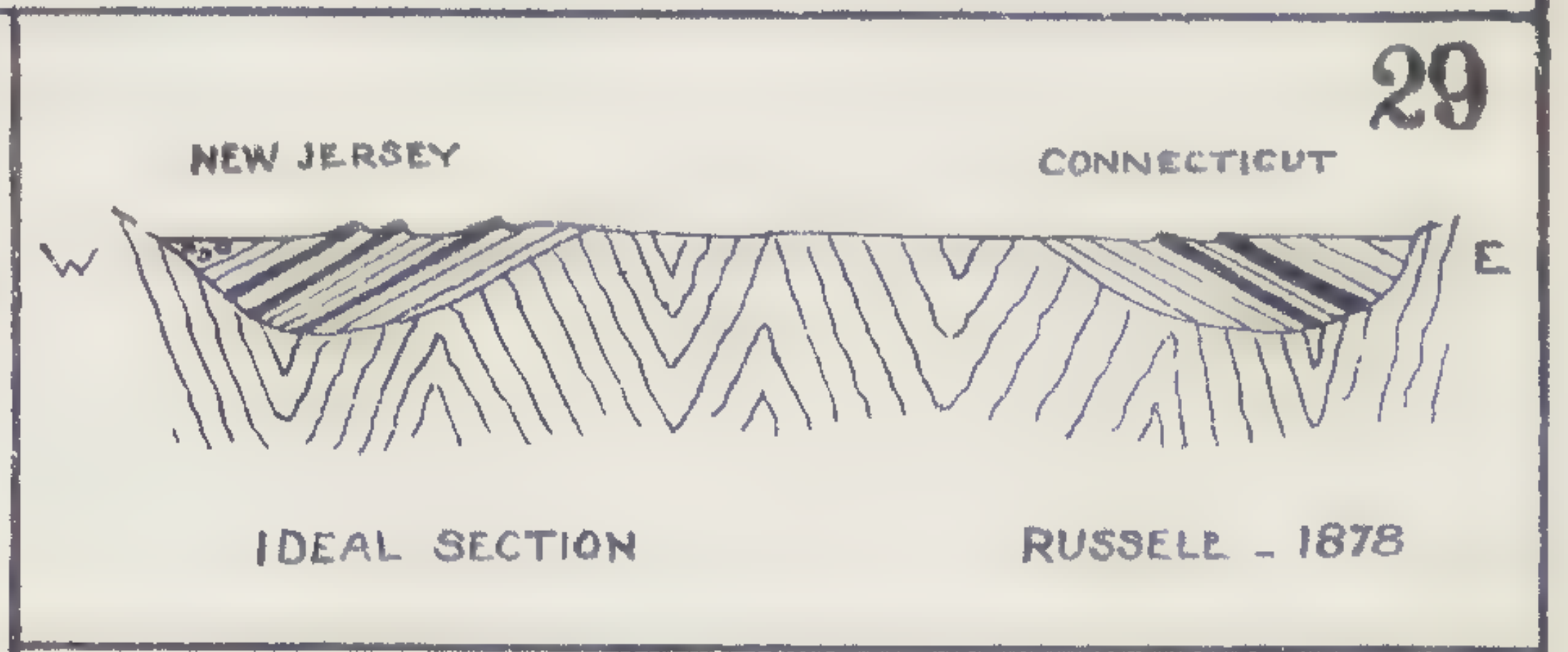

24
300'±
DIKE
N. CAROLINA
EMMONS 1858.

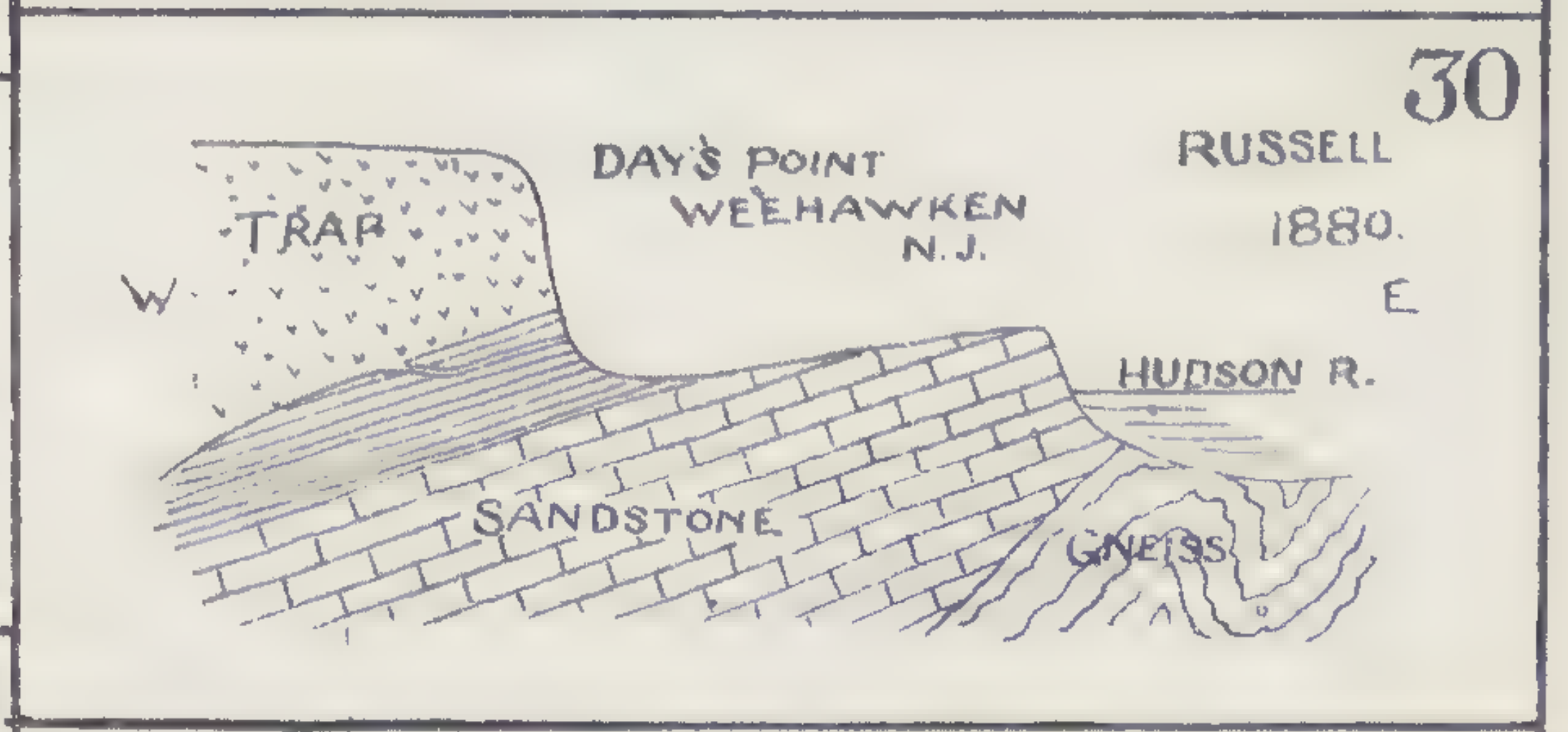

25
COOK, 1868.
W
drift on sh. & tr.
tr
PALISADES
sh
HUDSON R.
E

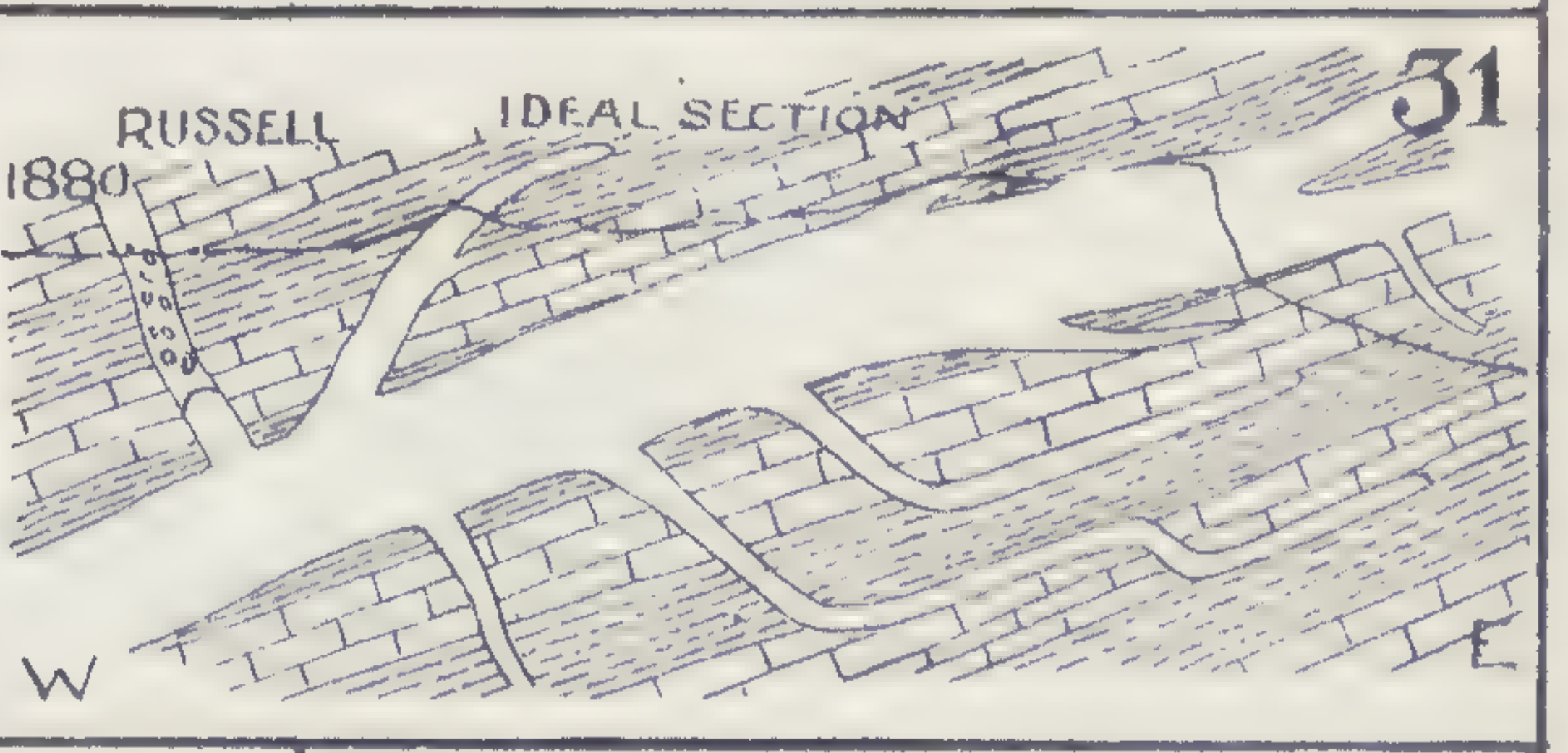

26
NW
(GILBO)
LAMBERTV.
GOAT HILL
BELLE MT
BALD PATE
SE
8 MILES.
EAST BANK OF DELAWARE R. BY LAMBERTVILLE, N.J.
COOK, 1867


27
NW ss. sh.
tr
sh
tr
ss.
sh.
SE
4 M. NW. OF GETTYSBURG, PA.
FRAZER, 1877.


28
ALL THIS ERODED
LECONTE 1878
W
E
IDEAL SECTION OF CONNECTICUT VALLEY.


29
NEW JERSEY
CONNECTICUT
W
E
IDEAL SECTION
RUSSELL 1878

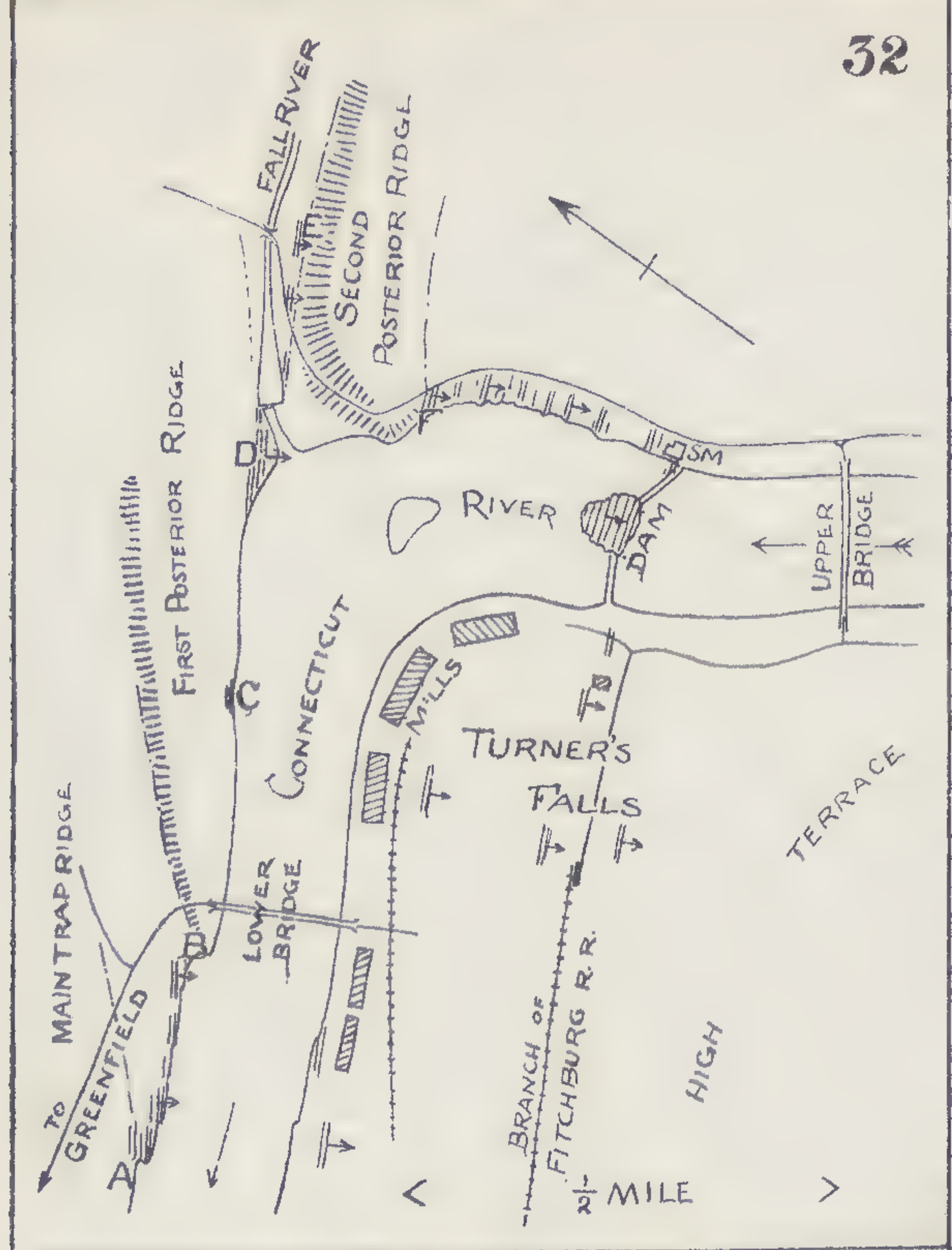

30
TRAP
DAY'S POINT WEEHAWKEN N.J.
RUSSELL 1880.
W
E
HUDSON R.
SANDSTONE
GNEISS


31
RUSSELL 1880
IDEAL SECTION
W
E

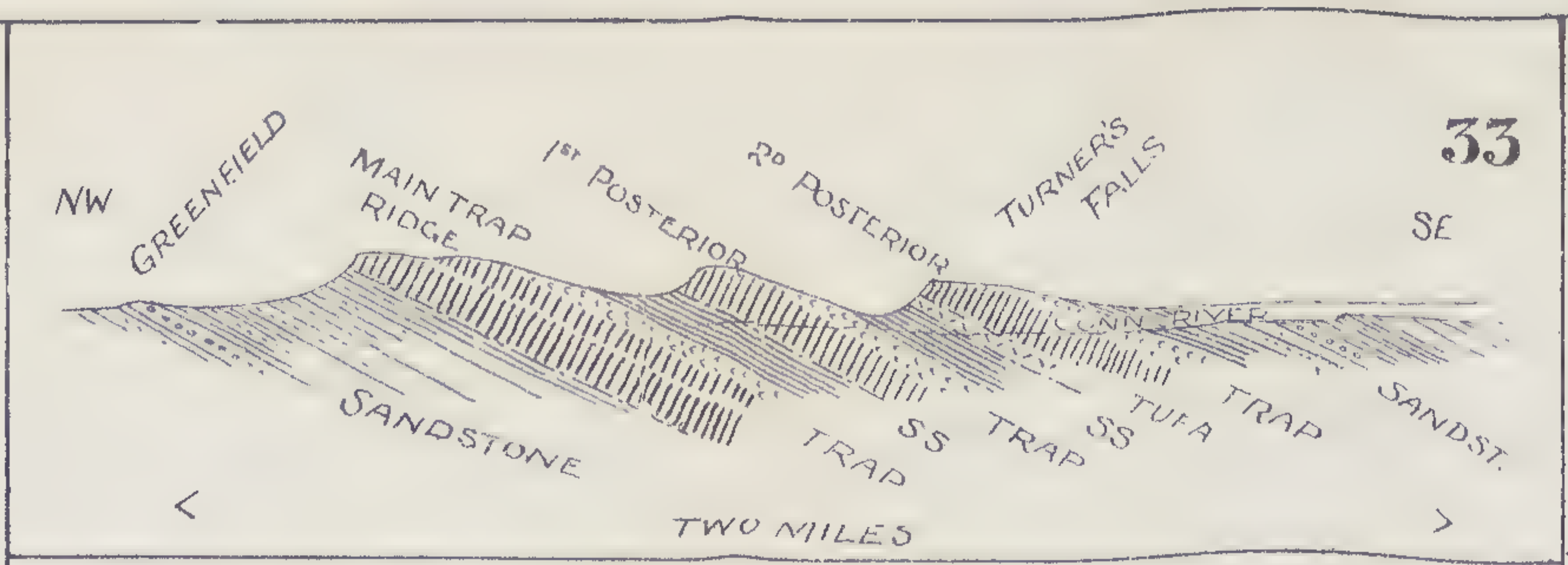
PICTORIAL REVIEW OF THE SUPPOSED RELATIONS OF THE TRIASSIC TRAPS AND SANDSTONES FROM 1818 TO 1880

COMPILED BY W. M. DAVIS.
1882

32

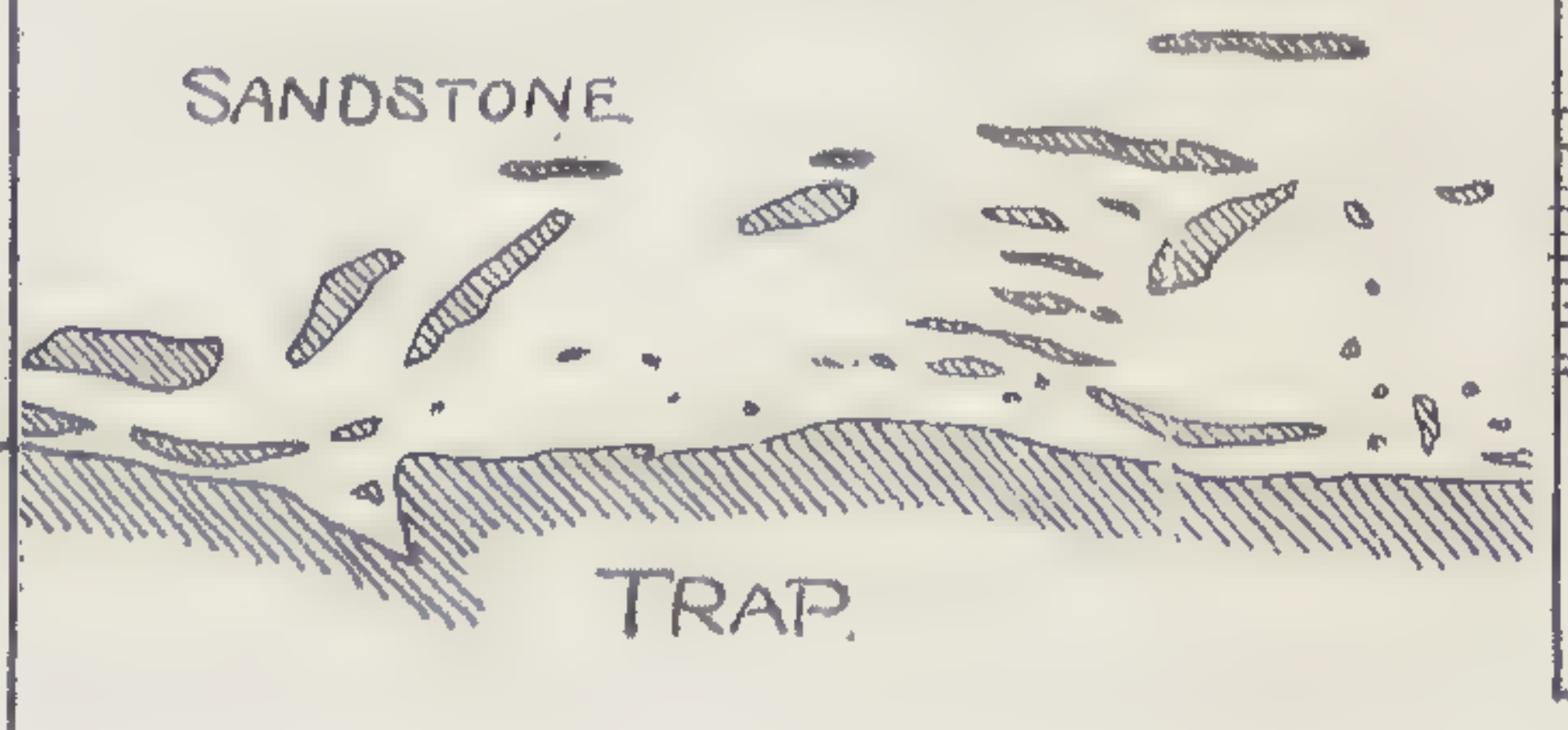

FALL RIVER
SECOND POSTERIOR RIDGE
FIRST POSTERIOR RIDGE
MAIN TRAP RIDGE
RIVER
DAM
SM
UPPER BRIDGE
CONNECTICUT
MILLS
TURNER'S FALLS
TERRACE
LOWER BRIDGE
TO GREENFIELD
BRANCH OF FITCHBURG R.R.
HIGH
A
B
C
D
½ MILE

33

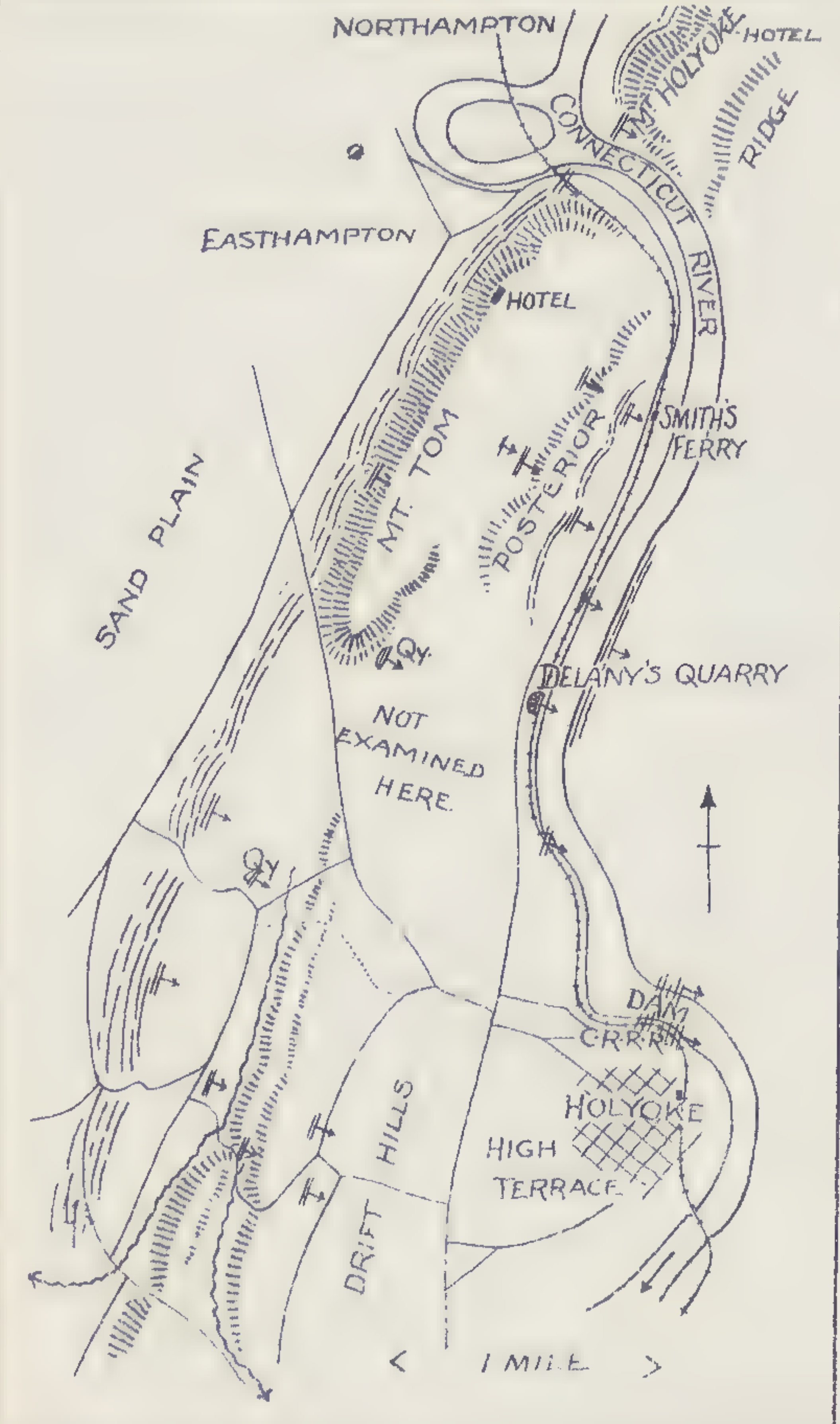

NW
SE
GREENFIELD
MAIN TRAP RIDGE
1st POSTERIOR
2d POSTERIOR
TURNER'S FALLS
CONN. RIVER
SANDSTONE
TRAP
SS
TRAP
SS
TUFA
TRAP
SANDST.
TWO MILES

34

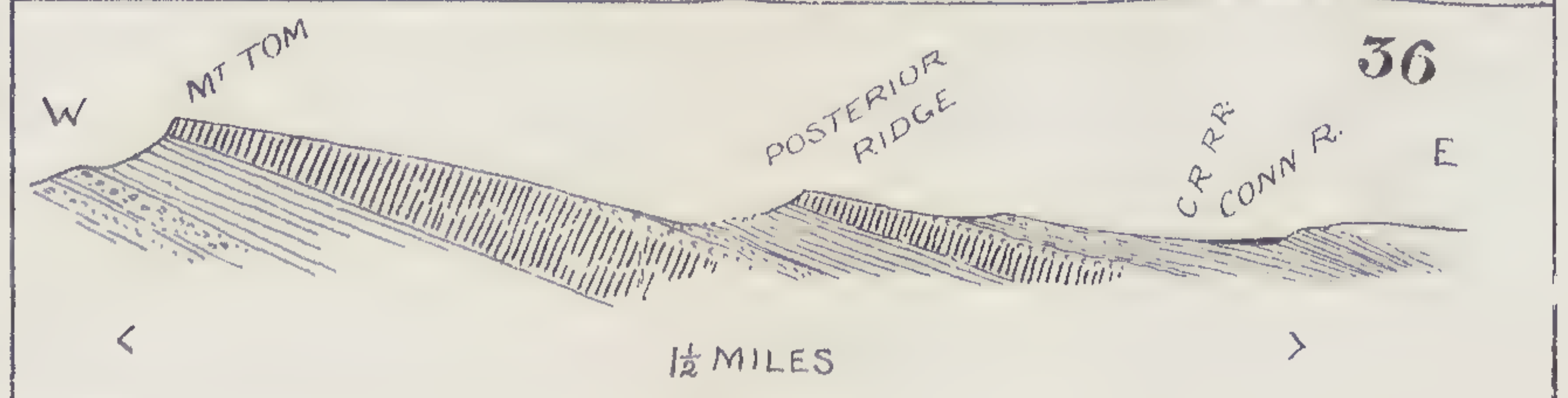
JUNCTION OF TRAP AND SANDSTONE TURNER'S FALLS.


SANDSTONE
TRAP.

35

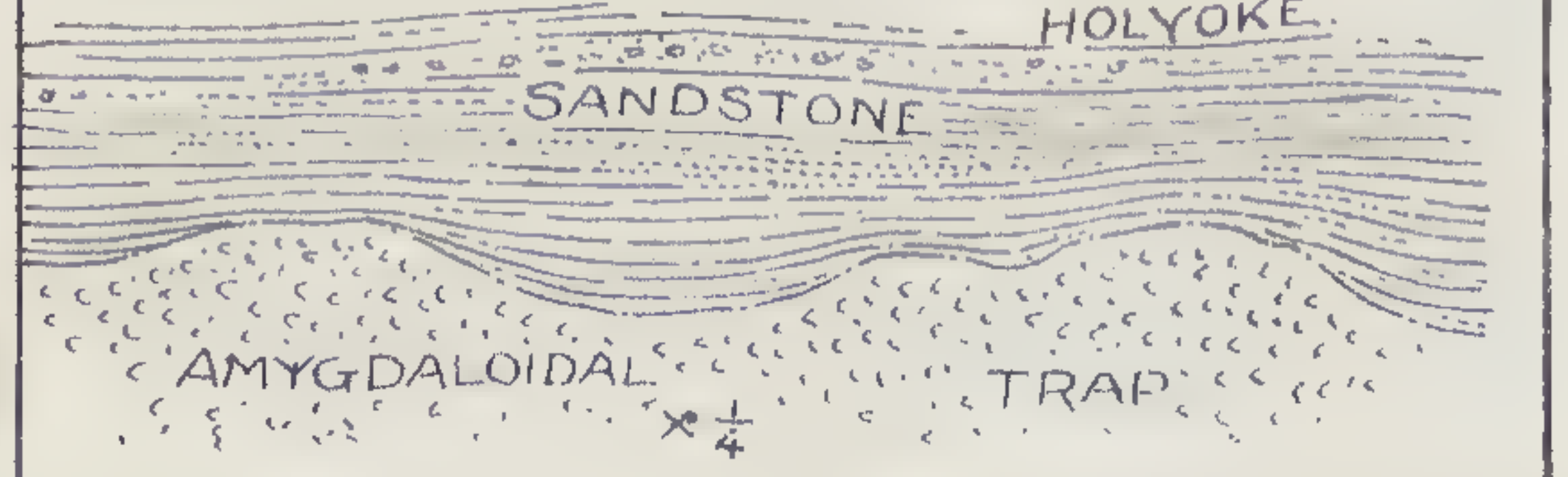

NORTHAMPTON
MT HOLYOKE
HOTEL
RIDGE
CONNECTICUT RIVER
EASTHAMPTON
HOTEL
MT. TOM
POSTERIOR
SMITH'S FERRY
SAND PLAIN
DELANY'S QUARRY
NOT EXAMINED HERE
DAM
C.R.R.
HOLYOKE
HIGH TERRACE
HILLS
DRIFT
1 MILE

36

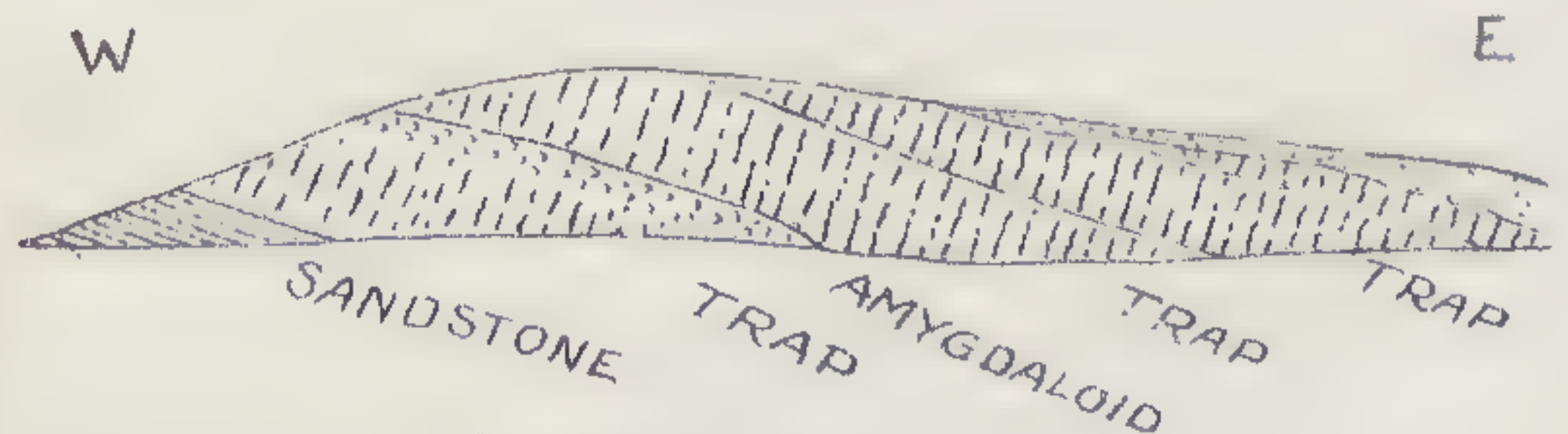

W
MT TOM
POSTERIOR RIDGE
C.R.R.
CONN R.
E
1½ MILES

37

GENERALIZED JUNCTION, DELANY'S QUARRY, HOLYOKE.

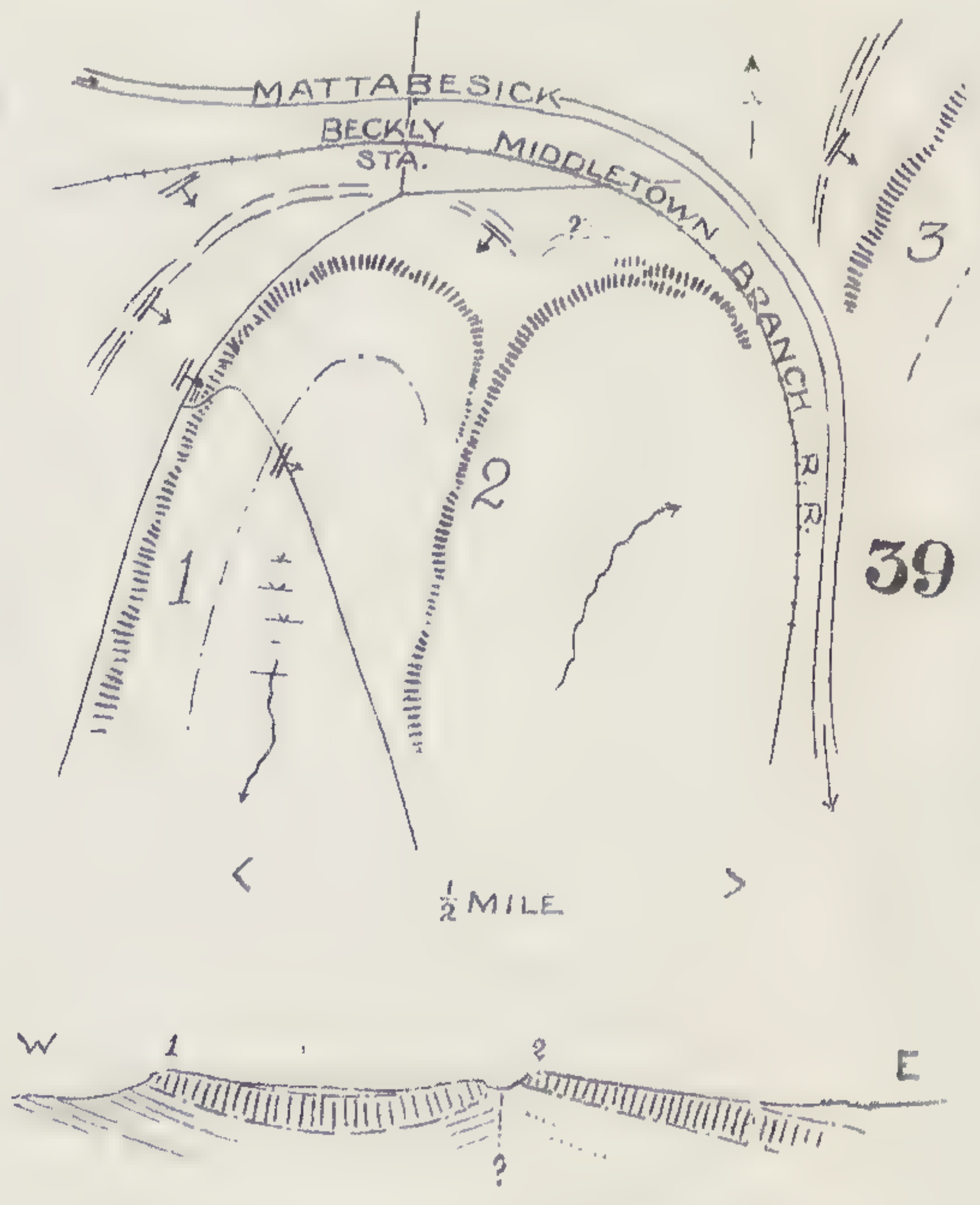

SANDSTONE
AMYGDALOIDAL
TRAP
× ¼

38


W
E
SANDSTONE
TRAP
AMYGDALOID
TRAP
TRAP

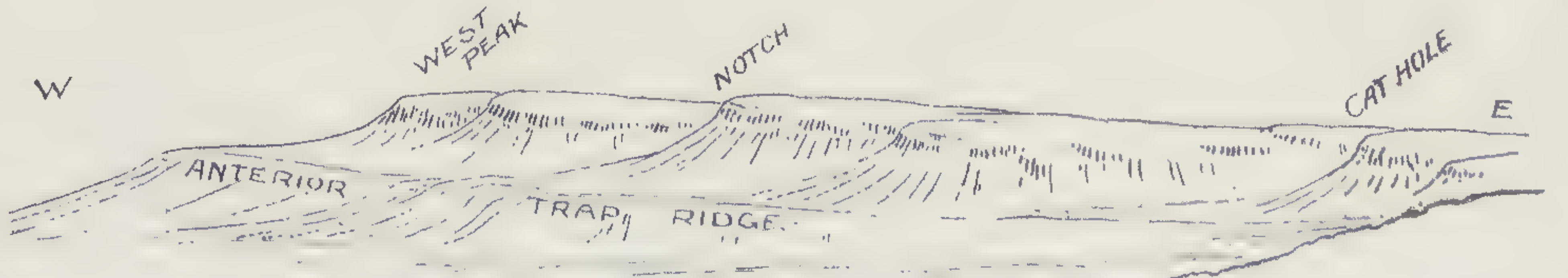
B.&A. R.R. CUT, WEST SPRINGFIELD.

39


MATTABESICK
BECKLY STA.
MIDDLETOWN BRANCH R.R.
1
2
3
½ MILE
W
1
2
?
?
E

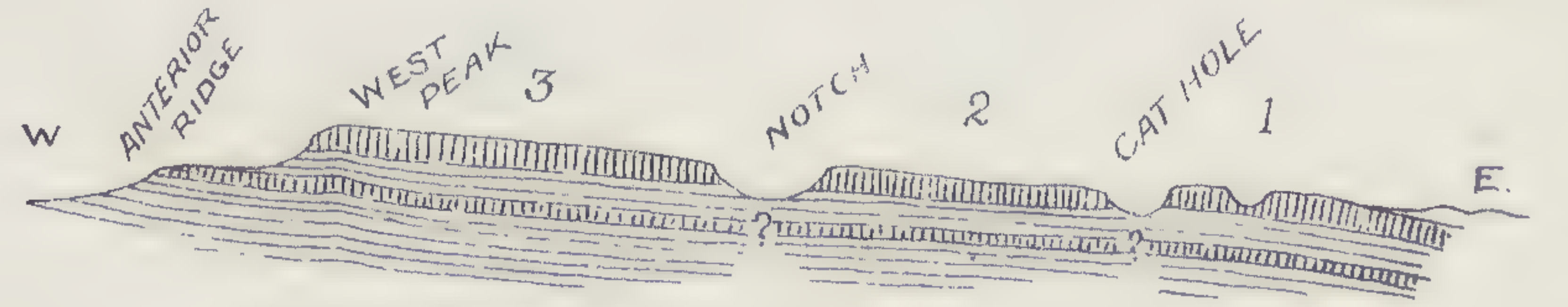
FOLD & FAULT IN TRAP SHEET.
BECKLY, CONN.

40


W
WEST PEAK
NOTCH
CAT HOLE
E
ANTERIOR
TRAP
RIDGE

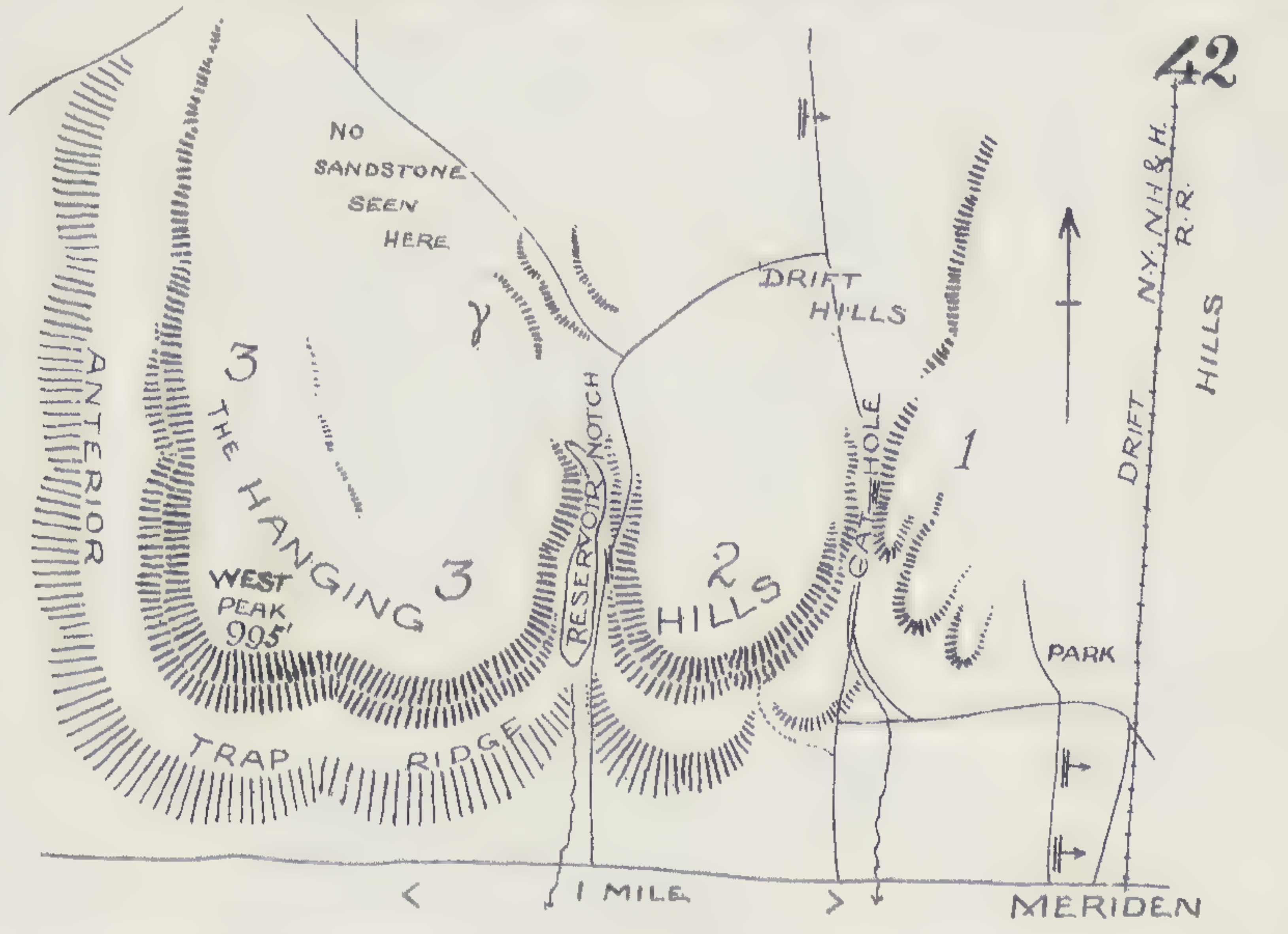
THE HANGING HILLS FROM MERIDEN

41

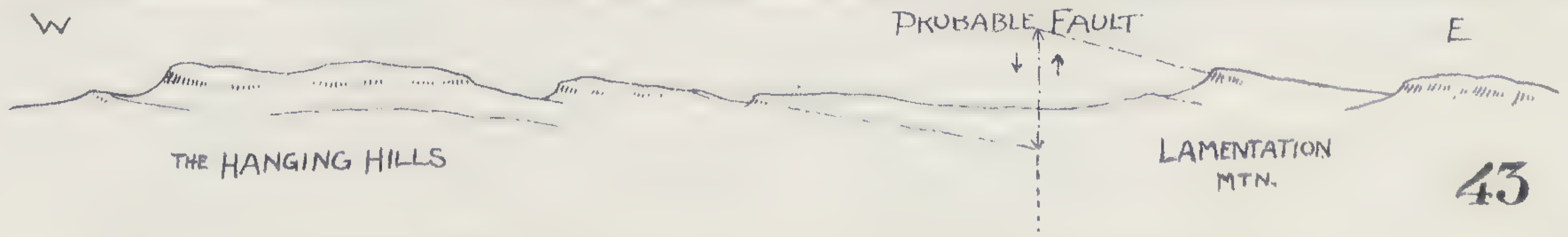

W
ANTERIOR RIDGE
WEST PEAK
3
NOTCH
2
CAT HOLE
1
E.
?
?

THE HANGING HILLS IN SECTION

42

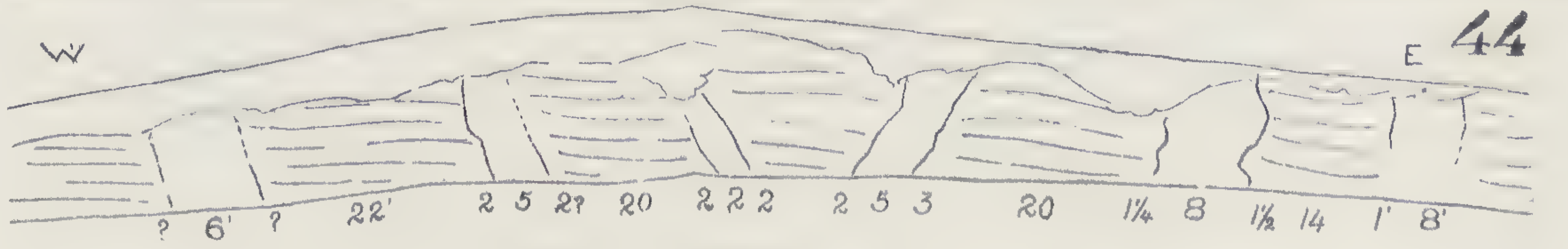

NO SANDSTONE SEEN HERE
γ
DRIFT HILLS
N.Y. N.H. & H. R.R.
HILLS
DRIFT
ANTERIOR RIDGE
3
THE HANGING HILLS
3
WEST PEAK 995'
NOTCH
RESERVOIR
2
CAT HOLE
1
PARK
TRAP RIDGE
1 MILE
MERIDEN

43


W
PROBABLE FAULT
E
THE HANGING HILLS
LAMENTATION MTN.

PROFILE SEEN NORTHWARD FROM MT. TOM, WALLINGFORD CONN.

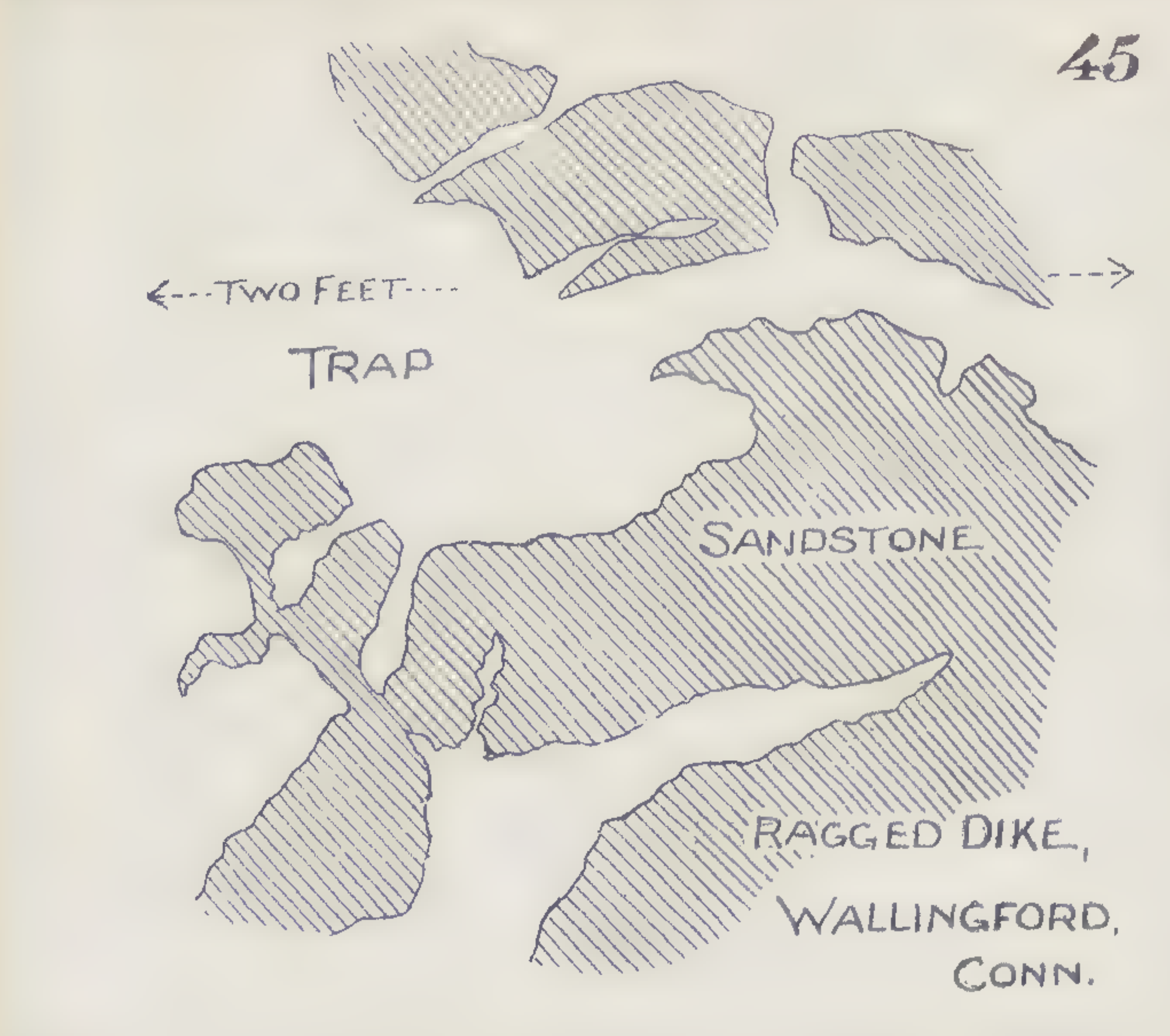
44


W
E
? 6' ? 22' 2 5 2? 20 2 2 2 2 5 3 20 1¼ 8 1½ 14 1' 8'

DIKES IN SANDSTONE.
ON THE ROAD FROM NEW HAVEN TO EAST HAVEN.

The Heliotype Printing Co. 211 Tremont St. Boston

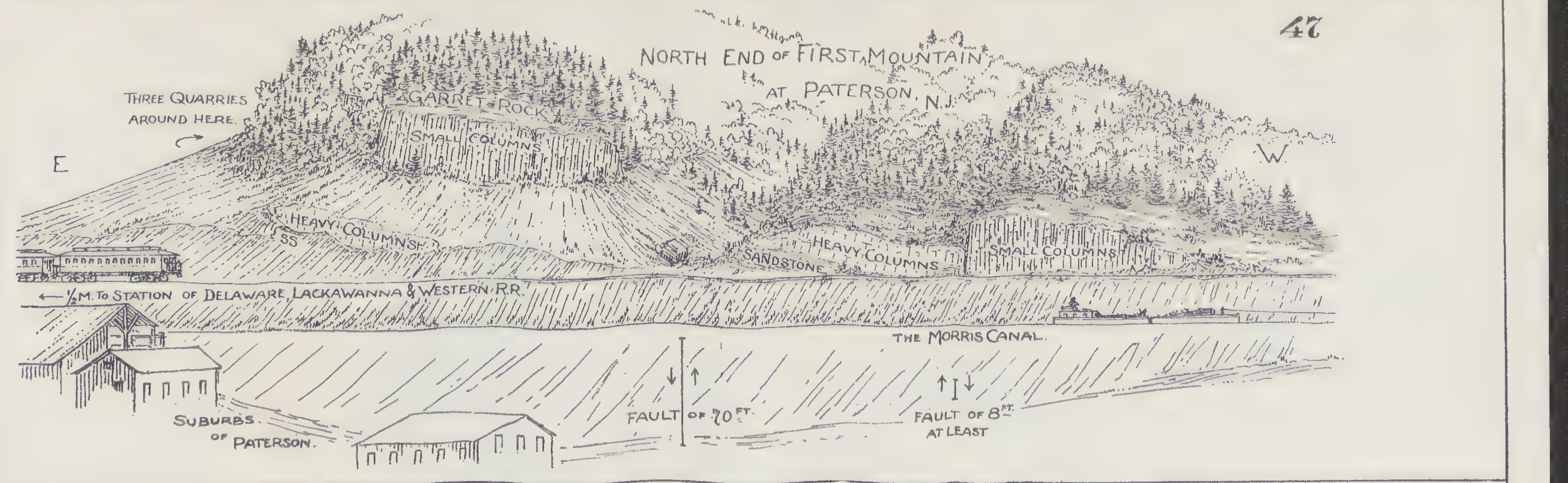
45



RAGGED DIKE, WALLINGFORD, CONN.

TWO FEET
TRAP
SANDSTONE

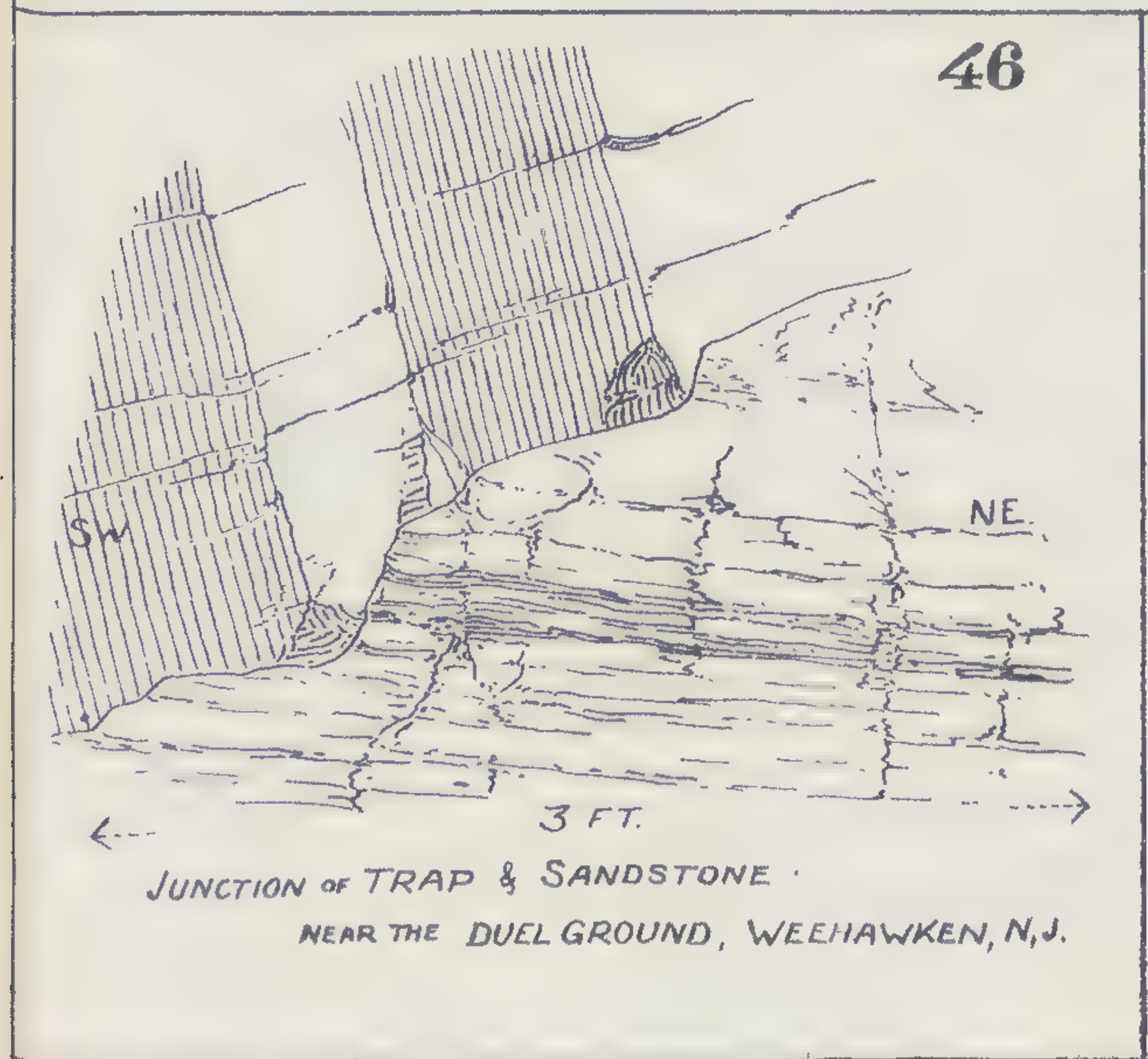
47



NORTH END OF FIRST MOUNTAIN AT PATERSON, N.J.

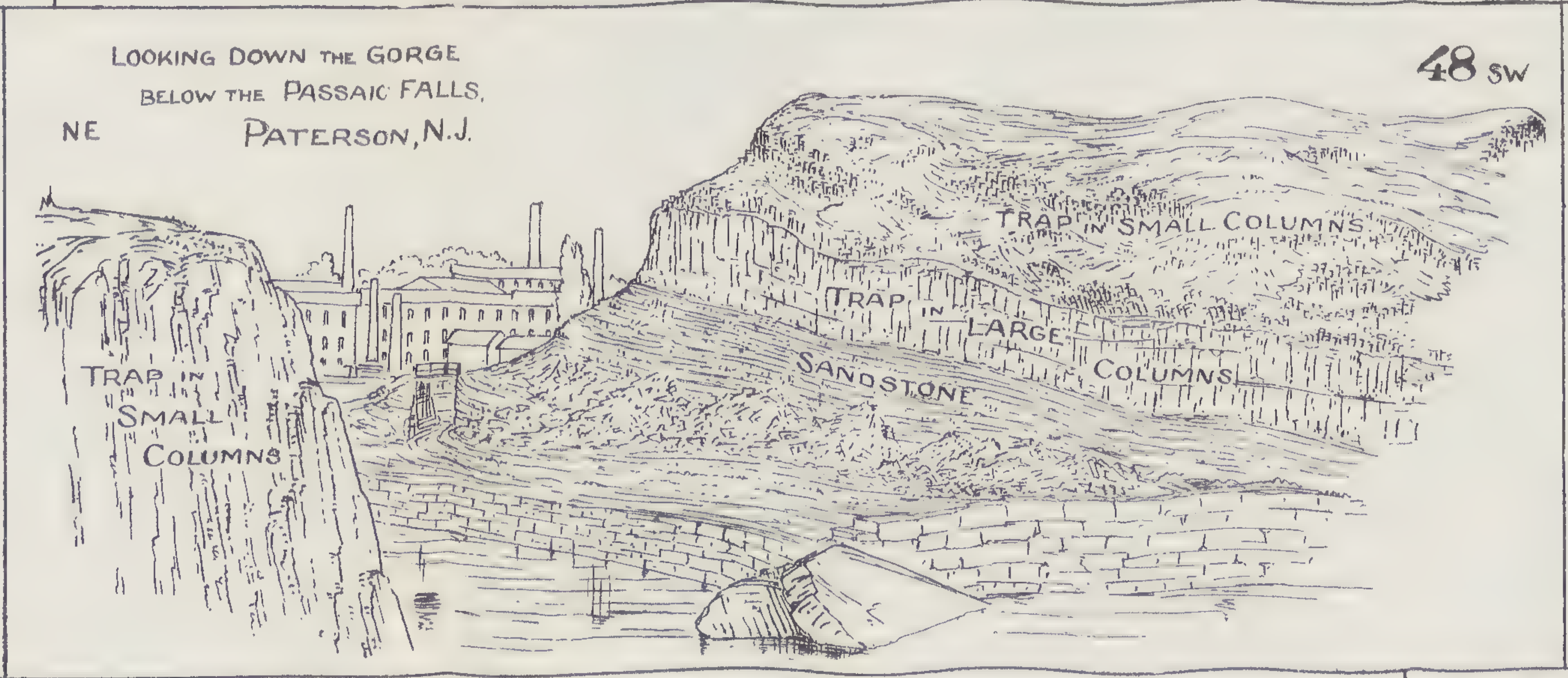
THREE QUARRIES AROUND HERE
E
W
GARRET ROCK
SMALL COLUMNS
HEAVY COLUMNS
SS
SANDSTONE
HEAVY COLUMNS
SMALL COLUMNS
½ M. TO STATION OF DELAWARE, LACKAWANNA & WESTERN R.R.
THE MORRIS CANAL
FAULT OF 70 FT.
FAULT OF 8 FT. AT LEAST
SUBURBS OF PATERSON

46



JUNCTION OF TRAP & SANDSTONE NEAR THE DUEL GROUND, WEEHAWKEN, N.J.

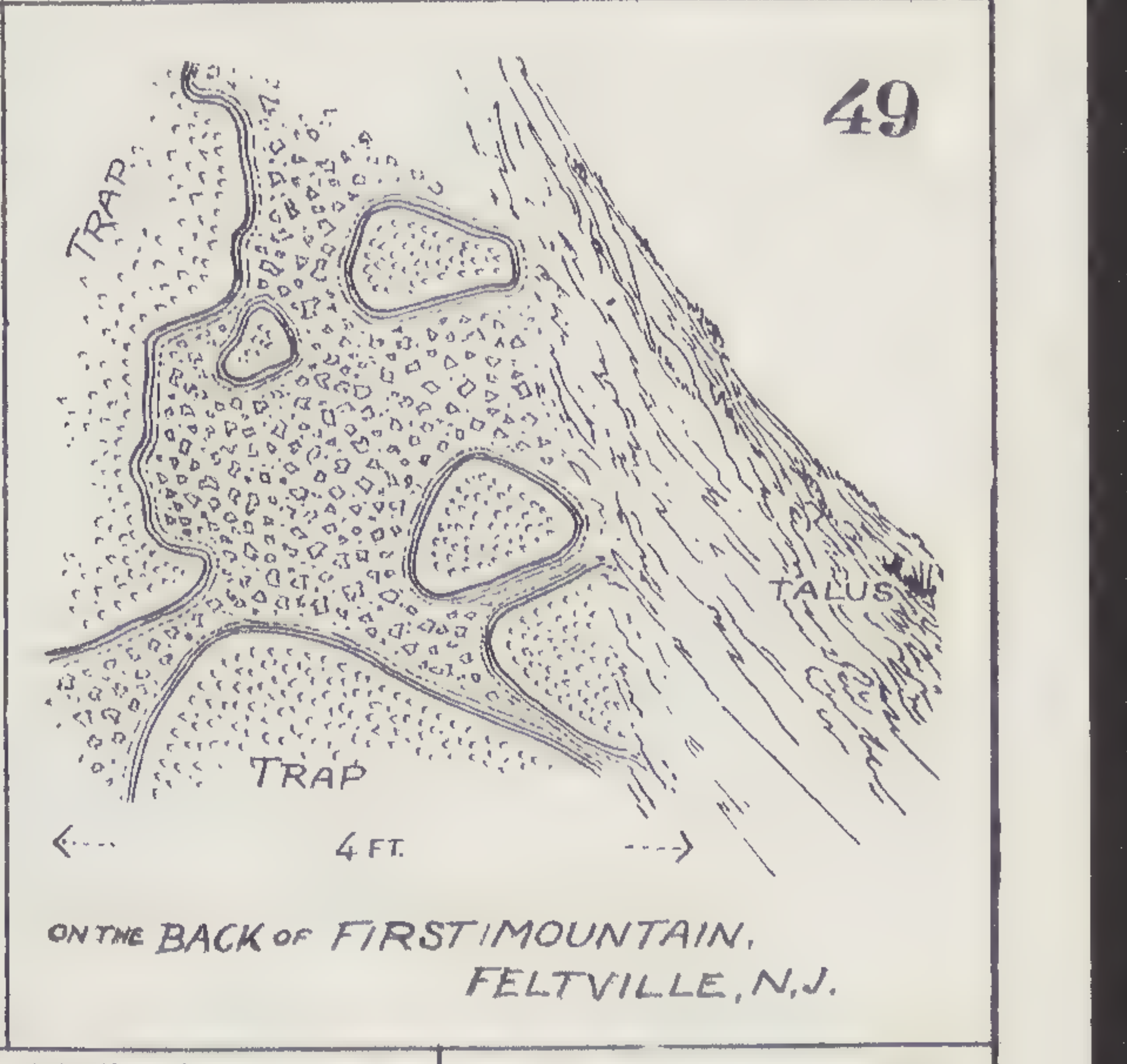
48



LOOKING DOWN THE GORGE BELOW THE PASSAIC FALLS, PATERSON, N.J.

SW
NE
TRAP IN SMALL COLUMNS
TRAP IN SMALL COLUMNS
TRAP IN LARGE COLUMNS
SANDSTONE

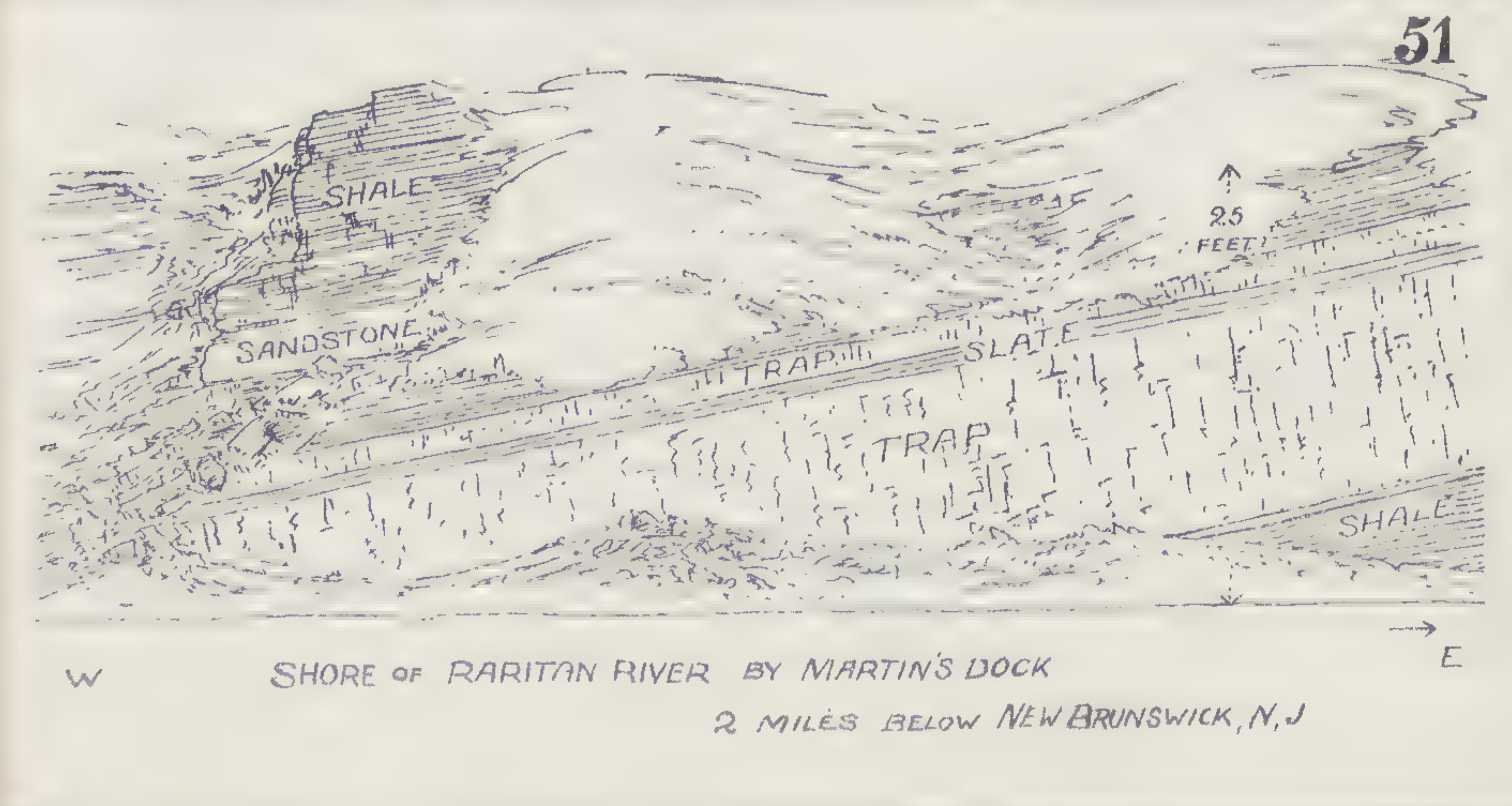
49



ON THE BACK OF FIRST MOUNTAIN, FELTVILLE, N.J.

TRAP
TALUS
TRAP
4 FT.

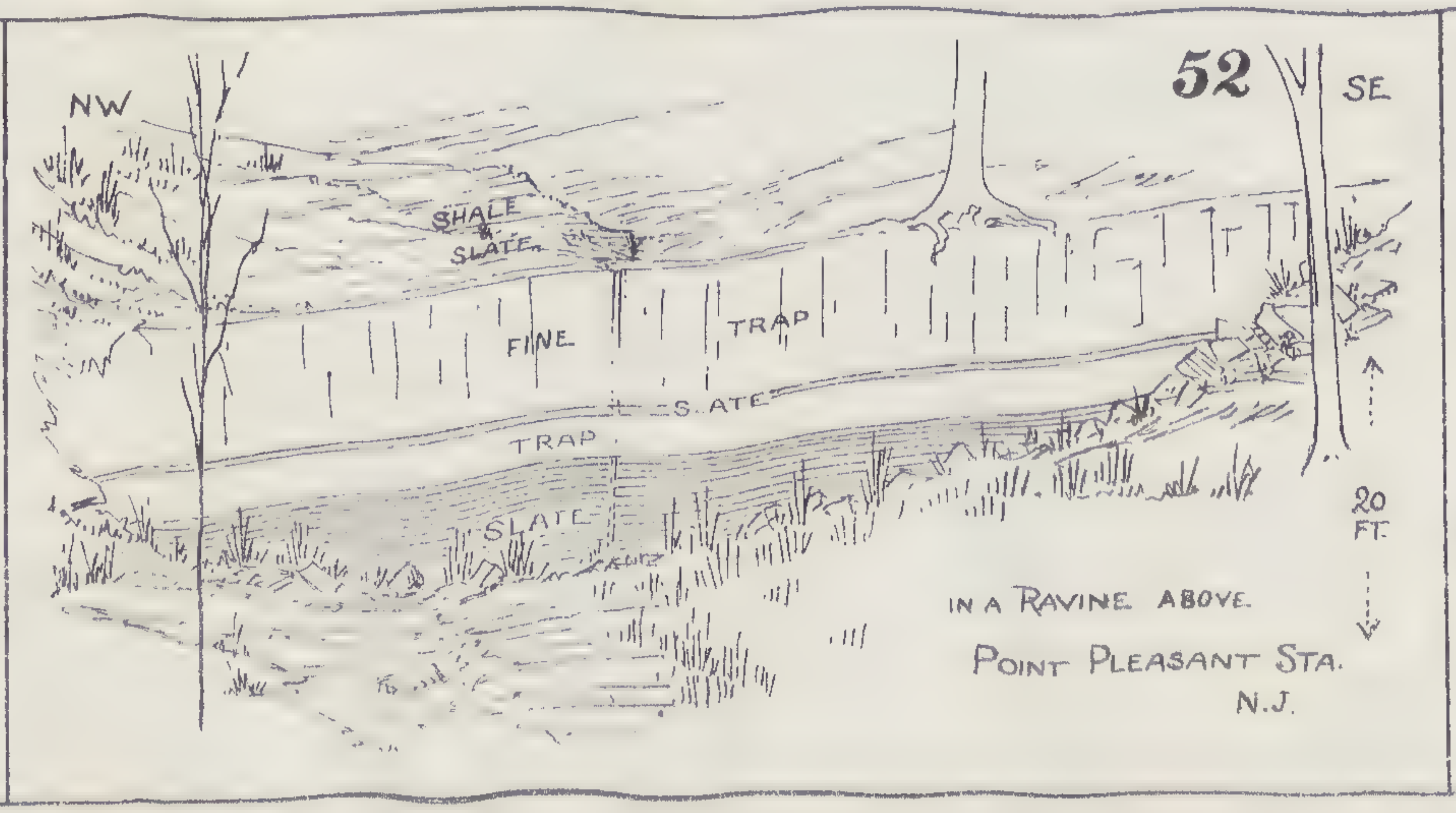
51



SHORE OF RARITAN RIVER BY MARTIN'S DOCK 2 MILES BELOW NEW BRUNSWICK, N.J

SHALE
25 FEET
SANDSTONE
TRAP
SLATE
TRAP
SHALE
W
E

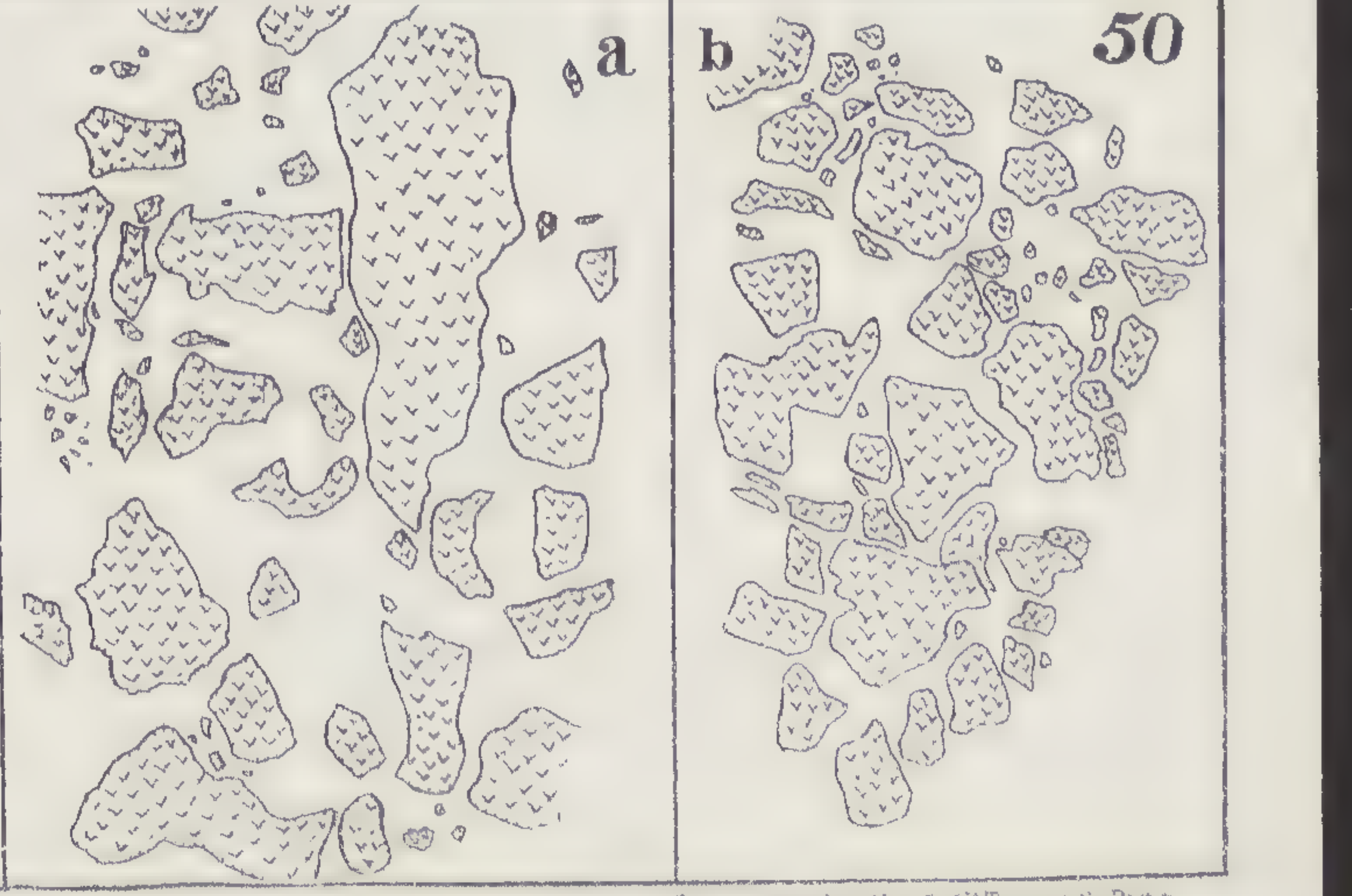
52



IN A RAVINE ABOVE POINT PLEASANT STA. N.J.

NW
SE
SHALE & SLATE
FINE TRAP
SLATE
TRAP
SLATE
20 FT.

50



The Heliotype Printing Co. 211 Tremont St. Boston.

No. 10. — *The Folded Helderberg Limestones East of the Catskills.*
By William Morris Davis.

Introductory. — Previous Descriptions. — Character and Sequence of the Formations. — *Hudson River Group.* — *Absence of Medina-Niagara Group.* — *Waterlime and Tentaculite.* — *Lower Pentamerus Limestone.* — *Catskill Shaly Limestone.* — *Encrinal and Upper Pentamerus Limestone.* — *Oriskany.* — *Corniferous Grits.* — *Corniferous Limestone.* — *Marcellus Shale.* — *Hamilton and Catskill Sandstones.* — The Question of Unconformity. — Paleogeography. — Folds and Faults. — *The Catskill Gorge below Leeds.* — *Other Points for Observation.* — *Unconformity by Faulting.* — *Compression in Synclinals.* — *Compression in Faulting.* — Surface Geology. — *Glacial Phenomena.* — *Stratified Clays.* — *Former Lines of Drainage.*

The Appalachian district in Pennsylvania is made up of three well-distinguished parts: a plateau of nearly horizontal rocks on the northwest, showing no formation younger than the Carboniferous and Upper Devonian; a rolling low country on the southeast, where the rocks are Lower Silurian and older, greatly folded and often half or wholly crystalline; an intermediate region, where the wave-like folds of the Paleozoic strata are best developed, and their effect in producing anticlinal, synclinal, and canoe mountains is best seen. If we trace these three belts northeastwardly into the Hudson valley, the first is well shown in the broad mass of the Catskills; the second in the perplexing Taconic region from the Hudson across to Western Connecticut and Massachusetts; but the third, so striking in Pennsylvania, has dwindled to a narrow strip of insignificant hills, only a mile or two wide, and a few hundred feet in height. Although so greatly reduced in size, this middle belt still retains its characteristic structure very clearly, and reveals this structure in its surface forms. The accompanying map represents a part of it some ten miles in length, the middle point of which is about west of the town of Catskill on the Hudson. Very little attention has as yet been given to this belt of miniature mountains, excepting in the study of its fossils. The following are the only descriptions referring to it that I have found.

W. W. Mather. Geology of New York; First District. Albany, 1843, pp. 317–352, 366–421. A general description is given of the several formations here occurring, their characters and sequence; but the structural peculiarities of the district are very imperfectly represented.

E. Emmons. Agriculture of New York. Albany, 1846. Vol. I. pp. 134–175, and Plates IV., XX., and XXI., bear more or less directly on the structure of our district.

N. S. Shaler. On the Existence of the Alleghany Division of the Appalachian Range within the Hudson Valley. American Naturalist, XI., 1877, 627, 628. A short notice of the extension of distinct anticlinal and synclinal structure to this point.

W. M. Davis. The Little Mountains * east of the Catskills. Appalachia, III., 1882, 20–33. A detailed elementary account of the structure of a small part of the Helderberg belt; with map and sections.

No geological maps of this region have been drawn on a large enough scale to show anything more than parallel strips of color along the western side of the Hudson valley. The little sketch-map in the last of the above-named articles, and the map accompanying this paper, are the first that show the well-marked Appalachian topography of the district.

The material for the present paper was obtained in part during two short visits in the spring and summer of 1877, the first in company with Mr. E. R. Benton, now Professor of Natural History in the University of Rochester; the second with Professor N. S. Shaler, Mr. J. S. Diller, and members of the Harvard Summer School of Geology. But a third trip made in the spring of the present year furnished fuller results; in this I was accompanied by Mr. J. E. Wolff, Assistant in Geology, and by Messrs. Bunker, Chase, Clark, Dean, and Jackson, students in Harvard College and the Lawrence Scientific School. To all of these I desire to give thanks for aid in making the observations herein recorded.

Our work was mostly stratigraphical, and some description of part of the results has already been published in *Appalachia*, as above mentioned. As only a short time was spent on the ground, the reader must expect to find some points indicated as probable, but not fully established; many of these would afford excellent subjects for detailed summer studies, and I should be greatly pleased to learn of their being taken up by residents or summer visitors.

The Silurian and Lower Devonian strata occurring in this part of the Hudson valley are the Hudson River sandstones and shales in the low country on the east by the river, and in occasional anticlinal valleys within the Little Mountain belt; next, the Lower Helderberg limestones, in good variety and well exposed at many points; over these the grits and limestones of the corniferous period; then the Marcellus shale in a valley, and the Hamilton sandstones in a line of bluffs limiting our district on the west. The latter sandstones or very similar ones continue to the foot of the Catskill Mountains in low ridges and shallow meadow valleys. Whatever paleontological evidence might be discovered by deliberate observation to justify these subdivisions, the lithological character is so distinct that fossils are hardly necessary, except in some of the limestones, for the identification of the several groups. The following table shows the sequence and thickness of the strata as described by several observers here by Catskill and a little farther south near Kingston.

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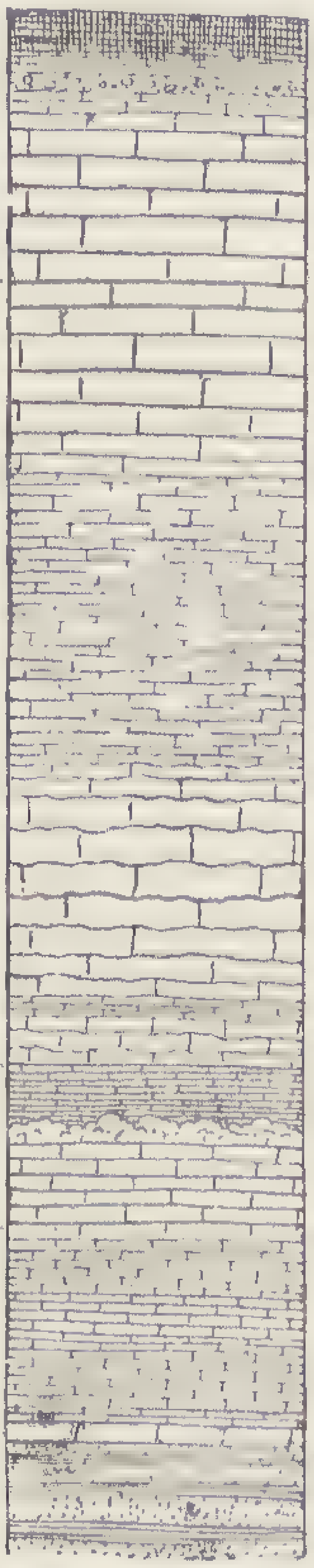
* This name was given by the writer to call attention to the peculiarly mountain-like structure and form of these limestone hills. They are not so known in their own neighborhood.



		Mather, 1843.	Emmons, 1846.	Lindsey, 1879.*	Dale, 1879.*	Davis, 1882.
Grits.	Calcareous gritty shales.					
Oriskany.	Fragmental	$\frac{2}{3}$–2	½			½
Upper Pentamerus and Encrinal.	Sandy limestone. Heavy and cross-bedded limestone.		25	25 30	20 20	120
Catskill Shaly.	Thin-bedded impure shaly limestone.		60–80	16	15–20	? 100
Lower Pentamerus. (Upper Ribbon.)	Knotted limestone.	50		25	20	80
Ribbon.	Fine-bedded.	100 to 150		6–8		70
Stromatopora.	Sponge-layer.			8		
Tentaculite.	Fine-bedded.			14		
Waterlime.	Shaly limestone.			40 ?		
Coralline.	....	....	......	6–8	6	?
Hudson River Group.	Shales and fine sandstones.					>1000

* As referred to below, page 321.

The remarkable absence of the Medina-Niagara series of formations between the Hudson River group and the lowest of the overlying limestones will be discussed farther on. Here by Catskill nothing was seen that could be surely referred to any of the missing formations; but Lindsey and Dale describe six or eight feet of Coralline or Encrinal limestone that they identify as some member of the Niagara series. The absence of the Oriskany sandstone is almost as complete.

The formations observed in our sections of the Little Mountains may be described as follows.

The Hudson River group consists of a great series of fine gray or brown sandstones and shales, with no layers here sufficiently marked to be recognized at their probably repeated outcrops. The layers sometimes contain flakes of many-colored clay with the fine sand, implying an erosion near the place of deposition, and some layers have an uneven surface like a mud-flow (see fig. 1). Irregular ripple-marks are common, and in good exposures they may be seen over large surfaces; but we found no cross-bedding or coarse sandy layers. No fossils were seen: their absence cannot be ascribed to metamorphism, either mechanical or chemical, for many of the strata seem very little altered in spite of the general disturbance. These rocks are well exposed at many points where they crop out above their usual terrace covering of clays and sands that are spread over all the low land; and are also shown on the creek sections, as on the bank of the Catskill at Catskill Village, where excessive and irregular plications may be seen (fig. 2); sharp folds, slickensides, and small faults are very common; and likely enough faults of larger throw occur, though they cannot be detected. A point of good continuous, and just now of fresh exposure, is in the railroad cut on the bank of the Catskill just below Austin's Mill; a fine dome-like fold is seen by the stream, and farther on broadly curved surfaces of rippled shales alternating with firm sandstones dip conformably under the limestones (fig. 3). Unconformity might well be expected: the Medina, Clinton, Niagara, and Salina series, about one thousand feet thick in Western New York and over six thousand in Central Pennsylvania, are all absent here, unless some few feet of nondescript beds may represent them.* The evidence of conformity and the possible meanings of this absence of formations are discussed farther on.

The beds of passage from Hudson River to Lower Helderberg were best seen on the road leading down to Austin's Mill (fig. 3), and at the north end of the Quarry Hill: they are sandy limestones, without fossils as far as observed, and not more than five or ten feet thick between characteristic Hudson River sandstones and shaly layers of the Waterlime.

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* If the shaly layers of the Waterlime are considered equivalent to the Salina, this must be a little modified.

There is no distinction attempted on our map and sections between the Waterlime and the Tentaculite limestone: all the calcareous layers below the knotted strata of the Lower Pentamerus are marked by a single color. Professor Hall (Paleontology of New York, III. 386) describes the Waterlime as being of "gray or drab-colored surface and darker interior color, and almost destitute of fossils"; while the Tentaculite is "a thinly bedded blue or black limestone, abounding in certain organic remains." These characters are easily recognized. The total thickness of seventy feet was measured on the eastern slope of the Quarry Hill, from the uppermost sandstone to the lowest knotted limestone. At Austin's Mills the measure would be less. The subdivisions of the Tentaculite, as described at Rondout (see Lindsey and Dale, as below), are here clearly made out. Some ten feet of fossiliferous limestone are followed by the Stromatopora layer, of one or two feet thick, with numerous sponges a foot or a foot and a half in diameter (fig. 4); next above come twelve feet of fine Ribbon limestone, in even parallel layers, shown by alternating bands of lighter and darker color, often as thin as one twentieth of an inch; then comes the coarse Lower Pentamerus, but about ten feet above its base there is a band of Ribbon limestone again, one or two feet thick. The even lines and smooth gray weathered surface of the Ribbon limestone frequently serves as a well-determined horizon, outcropping on the slope of the ridges made by the Lower Pentamerus.

The fossils of the Tentaculite limestone commonly seen are a *Leperditia*, a *Tentaculite*, *Orthis plicata*, and a *Turritella* (?). The first two are very common on certain layers. The thickness of the Waterlime and Tentaculite has already been mentioned as seventy feet or less. These two divisions of the limestone group are well seen — at least their upper members — at many points along the front of the Kalk Berg, around the synclinal outlier opposite Austin's Mill, and at the head of the southern anticlinal valley.

The change to the coarse, heavy, knotted layers of the Lower Pentamerus is accomplished within two or three feet. With this comes the frequent occurrence of dark chert in irregular masses up to six inches in diameter. The fossils easily found are *Pentamerus galeatus* (beaks are very common on weathered slopes in the soil) and *Atrypa reticularis:* both are common. The thickness measured about eighty feet on the eastern slope of the Quarry Hill. The best exposure is on the Catskill on the first bend above Austin's Mill, where broad surfaces of the limestone are laid bare; it is fairly shown in the ridges or bluffs all along its outcrop.

The Catskill (formerly Delthyris) shaly limestone is a rather evenly bedded, thin splitting, impure dull blue rock weathering gray or brown as its calcareous particles disappear. Fossils are very common, but on weathered outcrops are found only as casts: the ordinary forms are *Spirifer macropleura, Spiriferina perlamellosa, Streptorhynchus (Hemipronites) radiatus, Strophomena rhomboidalis, Rhynchonella ventricosa, Eatonia peculiaris*, and *Pterinea communis*.* The thickness of this division is somewhat under one hundred feet. The best exposure is at the railroad bridge across the Catskill, three quarters of a mile below Leeds, and on the banks farther down stream; but characteristic fossils are easily found at many points.

The Encrinal and Upper Pentamerus limestones were not separated in our study, as they constituted a single topographic element; but it was readily seen that crinoid stems were more plentiful in the lower than in the upper layers. The rock is hard, heavy-bedded, and coarse-grained, consisting of broken shells and crinoid stems; it is well adapted to heavy masonry; on some weathered joints, exposed in French's Quarry, very clear cross-bedding was seen. Corals make no important share of these limestones so far as we could discover. The shells recognized were *Pentamerus pseudo-galeatus, Spirifer cycloptera*, and many others not determined: they are so firmly held, that it is difficult to break out good specimens. The thickness of these two members as determined at the railroad bridge below Leeds is one hundred and twenty feet, but this may be exaggerated by local faulting. Other observers give it much less. French's Quarry and the Catskill bank by the railroad bridge give good exposures; and fair outcrops are found at many other points.

These Lower Helderberg limestones as a whole are decidedly harder than the shaly sandstones below or the grits above them, and are strongly determinant in forming ridges and bluffs. Among the most marked of these is the long, continuous ridge at their easternmost outcrop, known as the Kalk Berg (corrupted into Kalla Barrack †), where they are usually nearly vertical and sometimes are overthrown: other interesting forms of outcrop appear on the several synclinal and anticlinal folds.

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* The names are thus given in the collection in the American Museum of Natural History, New York.

† For these local names I am indebted to Mr. Henry Brace of Catskill.

The subordinate ridge-making members of the group are well shown in the Quarry Hill synclinal; they are the Lower Pentamerus, the upper part of the Catskill Shaly, and the Upper Pentamerus; while the Waterlime, the junction of the Lower Pentamerus and Catskill Shaly, and of the latter with the Encrinal, are marked by depressions. These relations of hardness are pretty constantly shown in all parts of our field, and add much to the ease of identification of the several subdivisions.

The upper part of the Upper Pentamerus becomes sandy and impure for about ten feet: this change is completed in the occurrence of a six-inch layer containing limestone pebbles up to an inch in diameter, and quartz grains of a quarter of an inch or less. Although no fossils were found in this thin conglomerate, I have considered it as representing the Oriskany sandstone, as it has the proper place in the series. Mather and Emmons describe it as half a foot to two feet thick. The best exposure of this layer was found on the north bank of the Catskill at Leeds, in the vertical strata on the western side of the anticlinal that shows there in the stream; and again at several points below, as far down as the railroad bridge.

The Grits which come next are fine-grained, dark gray or bluish, and generally with all appearance of bedding destroyed and supplanted by an imperfect, nearly vertical cleavage. Bedding planes are sometimes found, and generally contain impressions of the *Spirophyton cauda-galli.* Very few other fossils were found in this monotonous formation. Its thickness is three hundred and fifty feet, when measured by the breadth of outcrop where the enclosing limestones were about vertical, east of the limekiln near the junction of Old Kings and the Mountain roads. Other observers give only a fifth of this thickness. Outcrops are generally poor, as the rock usually weathers down to a rolling surface of gray gravelly soil, or is covered by swamps; the lower half of the Grits is more easily eroded than the upper: the gorge of the Catskill by Leeds presents on its southern bank an excellent section of the entire formation (fig. 5), and exhibits perfectly the relation between its true bedding and secondary fracturing. A small table-rock, over which a little stream falls on its way to the Kaaterskill west of West Berg, an eighth of a mile north of the limekiln above mentioned, shows many slabs near the top of this formation well marked with the cocktail seaweed.

The Corniferous limestone follows the Grits by an abrupt change; its layers are often massive, and always of a fine, close grain. Dark hornstone is very common in irregular masses often a foot broad; it is clearly of secondary origin. Fossils are scarce; the corals so common farther west are hardly seen here, but the fine, massive limestone was very possibly largely derived from a coral reef not far distant. There was no good place to estimate its thickness; but twenty-five or thirty feet, as given by Emmons, seems too small. The margins of this formation have a peculiar way of weathering out into large loose blocks, often ten feet cube; good examples are seen on Old Kings road just south of the Mountain road; near Van Luven's Lake; and north of Hooge Berg. The last-named point gives a good section of the limestone at its southern end, and it can be well seen at Leeds west of the Grits.

The Marcellus shale follows by a very abrupt transition, as may be seen at its only exposure, on the east bank of the Cauterskill, just south of the Mountain road bridge. It is a fine black fissile shale, in which a few faint fossil shells were found in 1877. Its upper limit and thickness were not determined, as it is throughout worn down into a valley between the Corniferous on the east and the Hamilton on the west, and deeply buried under stratified clays. The Hamilton sandstones and shales and the overlying formations were not examined closely; the lower layers of the former are well shown at the Big Falls of the Kaaterskill, where several strata are very fossiliferous; *Spirifer mucronata* and *medialis* are both of common occurrence. From the Marcellus valley to the foot of the mountains these and similar, but non-fossiliferous, sandstones and shales continue with a gentle westerly dip, and their thickness must amount to over two thousand feet. From the foot of the mountains to the summits of their broad masses, the strata are essentially horizontal, and may measure about three thousand feet more, chiefly of sandstones and sandy shales, with some conglomerates near the top. These are generally accounted of the Catskill formation. Cross-bedding is common throughout, and in a great part of the Hamilton group.

The most interesting question presented by this series of rocks turns on the absence of the Medina, Niagara, and Salina strata from between the Hudson River and the Lower Helderberg formations, and the possibility of unconformity at this point of the section. The following historic review will show what observations have been made and what views have been held on this subject in the Hudson valley.

W. W. Mather. Report of W. W. Mather, Geologist of the 1st Geological District of the State of New York. Albany, 1838. (2d Annual Report.) "Mount Bob and Becraft's Mountain are outliers of limestones, lying unconformably upon the subjacent slate rocks. I have traced these rocks within a few feet of their junction in many places." (p. 165.)

The same. Fourth Annual Report, 1840. The Hudson River slate group "is overlaid unconformably in many places by the various rock formations of more recent origin." (p. 212.) The common and hydraulic limestones at the base of the Helderberg series "sometimes rest unconformably upon the Hudson slate group, as at Lawrence's quarry, on the Rondout, opposite Wilbur (see fig. 6, copied from fig. 1, Pl. 26, Final Report, 1843); sometimes conformably on the Shawangunk grit, ... as at Rosendale and Lawrenceville, on the Rondout; sometimes on the red and variegated shales and grits that overlie the Shawangunk grits, as at the High Falls of the Rondout in Marbletown." (p. 237.) Lawrence's quarry is again mentioned (242) as affording "a fine exposure of the different strata, and the Hudson slates are seen *unconformable*, below the limestones." At Hasbrouck's quarries on Pine Mountain between Rondout and Kingston Point, the Hudson slate series dips 40–60° to E. S. E.; the overlying limestone and cement beds dip 80° W. N. W., "and this dip continues nearly uniform along this line of upheave to the 'High Rocks' above Kingston Point." (p. 242.)

The same. Fifth Annual Report, 1841. There is "a line of fracture and anticlinal axis" extending northward from New Jersey, passing Kingston and the district here mapped. "On the west side of this axis of fracture and elevation, the rocks dip to the westward at variable, but generally at small angles, while on the east side they dip at a high angle to the eastward, and are frequently vertical in their stratification." (p. 64.) Further reference to Becraft's Mountain is made on page 90; it is also said that west of the line of fracture "the superincumbent rocks overlie this [Hudson slate] series conformably in most places." The several Helderberg outliers known to Mather are Becraft's Mountain and Mount Bob near Hudson; another in Greenbush, between the Sandlake and Nassau roads, about two miles from Albany, first examined by Dr. Eights; and two others described by Eaton, one in the north part of Greenbush, five miles southeast of Troy, the other in the town of Schaghticoke, on the north side of Tomhannock Creek (p. 87).

The same. Geology of New York, First Distrct, 1843. Most of the observations are repeated from the Annual Reports, pp. 330–373. Becraft's Mountain is described in detail (p. 351) and figured (Pl. 24, fig. 6, here copied, fig. 7): no doubt is expressed of the unconformity there; but at Mount Bob (Pl. 38, fig. 1, here copied, fig. 8) it is said to be "apparent." "Although the actual junction of the rocks of the Hudson River group with those of the Helderberg division was not observed between Kingston and Catskill, they were seen in many places so *nearly* in contact, and unconformable, as to leave scarcely a doubt that they were really unconformable" (p. 374); and they are so shown in his section on Esopus Creek (Pl. 7, fig. 9, here fig. 9); the author suggests that the Hudson series may have been disturbed first only to the east of the "anticlinal axis," and, later, to the west with the overlying formations (p. 374). But his section (Pl. 38, fig. 14, here fig. 10) at Catskill shows conformity.

H. D. Rogers. Second Annual Report on the Geological Exploration of the State of Pennsylvania. Harrisburg, 1838. The sandstone and conglomerate of IV. (Oneida and Medina) are "displayed near Rondout, resting *unconformably* and with a gentle inclination upon the steeply uptilted, contorted, and disrupted strata of the immediately subjacent slates" (p. 37). In Pennsylvania, the conglomerate at the base of IV. contains fragments of the three earlier formations, showing a violent physical change; but no unconformity was noted there (p. 36).

The same. On the Correlation of the North American and British Palæozoic Strata. Brit. Assoc. Rep., 1856 (178–180). "Undulated Matinal rocks support horizontal Niagara or Scalent strata, with a lapse of two intermediate formations for some distance from the Hudson, westward along the base of the Helderberg range." (p. 178.) In the Mohawk valley, these formations approach conformity. Southwestward to Alabama there is neither lapse of formations nor unconformity, but a violent change in the rocks in passing from Hudson River to Medina strata; the latter contain fragments of earlier formed layers.

The same. Geology of Pennsylvania, 1858, II. (784–787). "From Gaspé on the Gulf of St. Lawrence, S. W. to the River Hudson, wherever the Matinal rocks appear in contact with any of the superposed formations, the former are either highly inclined and folded, or give evidence of disturbance and partial metamorphism, while the overlying strata display much less displacement and alteration." (p. 785.) Becraft's Mountain and Rondout (fig. 11, here copied from Vol. II. p. 785) are mentioned as points where the unconformity is distinct. It is said to exist "from Rondout to Schoharie" (p. 785).

E. Emmons. Agriculture of New York. Albany, 1846, I. The sections in the gorge of the Catskill at Austin's Mill and at Becraft's Mountain are drawn showing a conformable sequence of Waterlime on Hudson River layers (his sections 5, Pl. XX. and p. 136, here figs. 12, 13); at Rondout, the relation is represented as unconformable by faulting (fig. 17, p. 134, here fig. 14).

James Hall. Palæontology of New York, Vol. II. Albany, 1852.

"Along the base of the Helderberg, where the Clinton, Niagara, and Onondaga salt groups are very thin, the Oneida conglomerate is absent, and the shales and sandstones of the Hudson River group rise to within a few feet of the Tentaculite limestone or Waterlime group." (p. 1, note.)

The same. Palæontology of New York, Vol. III. 1859. The author repeats a doubt previously expressed as to the truth of the unconformity at Becraft's Mountain, and states that the Upper and Lower Silurians are conformable on the northern front of the Helderberg Mountains (p. 33, note). Farther on, he writes: "The Hudson River group, which constitutes a few feet of their [Catskill Mountains] elevation at the base, is disturbed, and the succeeding beds lie upon this unconformably" (p. 69); and again, "the unconformability of the Lower Helderberg group upon the Hudson River group" shows that the subsidence of the old sea bottom was periodical (p. 70; see also p. 88).

These are the older observations on the subject. The following references show the recent work, as well as the lack of agreement on the question in the two text-books in more general use.

J. Leconte. Elements of Geology. New York, 1878. "In the United States, the rocks of the whole [Paleozoic] system are conformable." (p. 277.)

J. D. Dana. Manual of Geology. New York, 1880. The making of the Green Mountains came at the end of the Lower Silurian (211, 212); the disturbance extended to the Hudson (214). Localities of unconformity mentioned are near Gaspé, near Montreal, and at Becraft's Mountain (216,* 241). The disturbance is thought not to extend southwestward of New Jersey (217).

J. G. Lindsey. A Study of the Rocks. Poughkeepsie Soc. Nat. Sci. Proc., II., 1879, 44–48, giving a careful description of the rocks at the Rondout cement quarries, and regarding the junction of the Upper and Lower Silurian rocks as unconformable.

T. N. Dale. The Fault at Rondout. Amer. Journ. Sci., XVIII., 1879, 293–295, from which figure 15 is here copied, showing the Lower Helderbergs, with a thin layer of Niagara (Encrinal) limestone at the bottom, lying squarely across the tilted Hudson River strata.

It would seem from this review that Mather and Rogers regarded the contact of the Upper and Lower Silurians as unconformable on both sides of the Hudson; Emmons figures a conformable relation, and considers the apparent unconformity at Rondout the result of a fault; Hall at first admitted the general unconformity, but later doubts it even for

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* Here Becraft's Mountain is wrongly said to be west of the Hudson.

Becraft's Mountain (but not for Rondout?). Leconte, on I know not what authority, takes a view opposite from the generally accepted one given by Dana. Lindsey and Dale both represent the junction at Rondout as an unconformity.

West of Catskill, I am persuaded that no unconformity exists: the evidence for this conclusion is given below. Becraft's Mountain and its smaller neighbor I have not seen, except from the railroad in passing: the opinions concerning this important point are contradictory, Mather and Rogers being opposed to Emmons and Hall. About Rondout no disagreement is directly expressed except by Emmons; and yet none of the observations or figures of the hill-sections in that district are conclusive; none enable the reader completely to exclude the possibility of the apparent unconformity being really a junction by faulting. It would seem, therefore, that all this subject needs reviewing.

The observations on which I rely to prove the conformable sequence of the strata in the district here mapped are as follows: —

First. At the north end of French's Quarry Hill, by a good spring on the middle one of the three roads that run around the slope, there is a contact of sandstone and an impure limestone clearly shown for some ten feet. The rocks here lie horizontal in the axis of a synclinal fold; their strata are closely parallel, and evenly superimposed; going down hill several outcrops of sandstone may be found; ascending to the south, the several limestones of the Lower Helderberg group are easily recognized in proper order; going east or west, the Hudson River strata soon rise from the synclinal axis, becoming steeper and steeper by gradual change.

Second. In the road and railroad cuts just east of Austin's Mill on the Catskill, the absolute contact is hidden by about ten feet of detritus, but the strata show only parallel arcs of the eastern half of a synclinal (see fig. 3). The apparent unconformity in the limestones here shown is due to horizontal faulting in the trough of the fold, as is described farther on.

Third. Along the front bluff of the Kalk Berg, generally marked by vertical strata of Waterlime and Lower Pentamerus, the sandstones are also vertical and parallel in strike; in the anticlinal valleys within the belt, the sandstone is perfectly conformable to the curves of the limestones, but no absolute contacts were found.

We therefore must conclude that the entire series is conformable in this district, and is folded together; and so it is represented on our sections.

When the attempt is made to restore the geographic changes by which the several strata were made to vary, it cannot be denied that this conformity is difficult to understand. The sands of the Hudson River group indicate a return of the shore line on the east after the open ocean conditions of the Trenton formation;* the shallowing of the waters and the westward advance of the shore continued certainly as far as the present line of the Hudson. If the unconformity at Becraft's Mountain be accepted, then we may follow the generally allowed belief in the folding of these sandstones accompanied by their elevation and erosion; and the very variable composition of the Niagara group as a whole, and the probable changes of level during the Onondaga (Salina) period are most likely to be explained by the oscillations of the adjoining land on the east during the Green Mountain growth. Excepting the few feet of beds found at the northern end of the Quarry Hill, which were not definitely referred to any group, there is nothing to be seen in the Catskill section to represent this vast lapse of time; for directly and conformably above the Hudson River sandstones come the Lower Helderberg limestones, which mark the second and greater eastward advance of the sea in the Upper Silurian, the first being that of the Niagara limestones. The present Catskill district cannot then have been dry land, for it shows no eroded surface beneath the Lower Helderbergs so far as we could discover. It could hardly have been far under water, for then it should have received some share of the various sediments so plentifully supplied to the ocean farther west and southwest. It may, therefore, be best to suppose that our district lay just off shore, or almost between wind and water, and either received very little detritus, or else was alternately covered and swept bare again by shoal water currents, so that in the end it had gained scarcely any rock material.

The change that followed next was not so much a depression of the ocean floor as a distant eastward retreat of the shore line; for the Lower Helderberg limestones show shallow waters, with freedom from shore sediments such as the Green Mountain rocks could have furnished. The Catskill shaly limestone probably marks a slight departure from this open ocean, and the presence of a neighboring shore, for it contains much more non-calcareous material than the limestones above and below it.

This second oceanic cycle ends with the Oriskany sandstone, marking a return of the shore, though perhaps not a very near approach; and a third cycle culminates in the Corniferous limestone, with deeper water here than the second. The Marcellus shale, which follows abruptly, seems too fine-grained and even-bedded over large areas to mark either a change to shallow water or a neighboring shore; the disappearance of the limestone below it was more probably connected with a further deepening of the water, or with a change in its temperature. But shallow water and near shore conditions came very clearly in the cross-bedded Hamilton and higher sandstones, and even more distinctly in the Catskill conglomerates.

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* See Professor Newberry's "Circles of Deposition," &c. Amer. Assoc. Proc., XXII., 1873, (2,) 185–196.

It is difficult to say what is here meant by "shallow water," for we know too little of the winds and currents of these old times. But the meaning of "near shore" can be estimated from the Catskill conglomerates, the coarsest of the entire series here seen from the Hudson River upwards, and therefore probably nearer their source than any of the other fragmental strata; and yet the crystalline rocks from which their pebbles have been chiefly derived cannot be less distant than the Highlands of the Hudson (forty miles), the same series of rocks in Connecticut and Massachusetts (forty), or the Adirondacks (sixty miles), for all the intervening areas, even if then exposed to erosion, were of non-crystalline rocks. "Near shore" does not, therefore, necessarily imply a very close neighborhood to land; and the carrying power of the paleozoic currents must have been very considerable. The identification of the source of the Catskill conglomerate pebbles is an interesting and important piece of work.

Folds and Faults. — The folds of small radius and varying form into which the above-described strata have been pressed, and the strong influence of the rocks' attitude on the surface form, combine to render this district an excellent training ground for Appalachian work. I know of no other where so many structural problems are as well shown within so limited a space. Two well-known features are clearly seen: the folds become more pronounced in going eastward, and all the anticlinals have their steeper dips on the west. Points of special interest may be named as follows.

The Catskill gorge from Austin's Mill up to Leeds gives a very fine series of natural sections. The railroad cutting and the lane leading up from the mill to the turnpike give good evidence of the conformity of the Hudson River strata under the limestones, and the Waterlime here presents two interesting forms of distortion. The first is an unconformity by horizontal faulting (fig. 3); the layers have been shoved past one another on an oblique crack. It is worth noting that a similar style of dislocation would probably be called true unconformity if it had taken place and been laid bare just at the junction of this formation with the Hudson strata below it; but happening twenty feet higher, it can be referred to its true cause. Secondly, we may note the effect of internal disturbance in the limestone, shown by the breaking up of some of its fine layers (fig. 16): this must be referred to the epoch of general folding, for examples can be found of all sizes up to a coarse brecciated mass several feet thick near the fault-unconformity; it is therefore an example of what Heim calls folding with fracture, as distinguished from folding by bending; and is explained by him as a folding that took place under a pressure of superincumbent rocks insufficient to cause plasticity in the brittle strata.* This fact may some day yield a measure of how many hundred or thousand feet of rock were *not* over the Waterlime when it was folded, and so lead to a conclusion respecting the former eastward extension of the Hamilton and Catskill sandstones.

Another conclusion may be noted: the strata showing these crowded layers lie near the axis of a synclinal trough, where it is often stated that folding produces tension, not compression. Scrope, for instance, compares folded strata to a bent board, which of course is stretched on its convex side.† Such a comparison is incorrect. None of the deep-lying rocks can escape compression during their folding: this can happen only to the superficial strata of the anticlinals. That synclinals are actually compressed, and not stretched, is shown by the growth of subordinate folds often found in their troughs; by the cleavage of slaty rocks at such points; and in general by the thickening of (argillaceous) strata at the turns and the thinning at the shanks or tangents of the folds, as was long ago pointed out by Sir James Hall,‡ and lately confirmed by Heim.§

Across the stream from the mill is a well-formed synclinal outlier (see Emmons, Pl. IV.) capped with Lower Pentamerus and perhaps with some Catskill Shaly limestone. Farther up the gorge, where the stream turns to the rock-strike, there are excellent exposures of Lower Pentamerus on the eastern (left) bank, and of Catskill Shaly opposite; the latter dips gently to the west at this point, but following it one third of a mile south, it becomes steeper, and at last is overthrown so as to dip 50° to the east. Above the next band, about at the middle of the west-east course of the stream, on the north bank, a distinct fault may be seen at the side of the railroad. The plane of the fault dips 45° east; on the western side, the Upper Pentamerus has a smooth, well-rubbed wall; on the east, the Catskill Shaly ends more unevenly, and supplies a quantity of fragments for the two feet of fault-breccia. There is no noticeable contortion of strata on either side. This example is interesting as it is a violation of the so-called "law of faults," (which I believe is no law at all,) for the upthrow overlies the hade. In this particular it confirms the hypothetical attitude of the fault-planes as generally drawn in Appalachian sections by Lesley and others, although these seldom if ever depend on direct observation. The example is further of use in showing that the fault may result from the same compressing force as the fold; and not from horizontal tension, such as is needed for the so-called normal fault. The throw here on the bank is probably fifty or seventy feet; it could be closely measured by more leisurely observation. We succeeded in finding the apparent continuation of the same fault half a mile to the north, but the intervening details of the map need revision. On the next turn of the stream by the railroad bridge, the upper limestones are finely shown on the east bank; on the other side, an obscure fold or fault complicates their succession. The grits and the thin Oriskany layer in the gorge at Leeds have already been mentioned.

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* Mechanismus der Gebirgsbildung, 1878, II. 31.

† Volcanos, pp. 51, note, 289.

‡ Edinb. Phil. Trans., VII., 1815, 97. § *Loc. cit.*, II. 48.

A cross-fault probably determined the gap on which the Kaaterskill turns eastward from the Marcellus at the saw-mill; for the folds do not correspond on the two sides of the gap, and the vertical limestones of West Berg seem displaced where they reappear on the north.

Other points of interest are as follows, beginning at the north end of the map: — Black Lake and a high hill next west of it; the hill is a saddle of grits on a limestone anticlinal; a rare occurrence. Canoe Pond and the steep plunge of the limestone under its eastern side. A Corniferous arch on either side of a little cross valley through which the railroad passes south of Leeds. The Quarry Hill synclinal and the Fuyk Valley anticlinal. The long tongue of Corniferous running down to Van Luven's Lake, and the large loose blocks of limestone at several points along it. The southern anticlinal valley, and the narrow faulted grit synclinals to the east of it. The way in which the several limestones wrap around the disappearing anticlinals is beautifully shown.

Surface Geology. — Glaciated rock surfaces are very seldom seen within the Little Mountain belt, but this is merely because the rocks are generally too weak to hold them. The firmer sandstones of the Hudson River group to the east show them abundantly, as on a large knob of rock alongside of the Mountain road in the village of Catskill just west of the stream; its steep northern slope gives a good small example of an overhanging polished surface. The only case of glacial action noted on the limestones was on the western side of the Corniferous anticlinal, where the Kaaterskill has recently cut away the protecting clays, just south of its cross valley by the saw-mill: these striæ are very well preserved; they run horizontally along the steep limestone stratum, parallel to the valley. The Hamilton and Catskill sandstones west of our limestone belt preserve many and distinct scratched surfaces: the largest of these was found on a bare even bed of rock on the Mountain road at a four-corners, about half-way from the Marcellus valley to the foot of the long grade; they bear S. 20° W., and some are continuous for fifty feet. A little farther west the same direction is repeated, and with it there are many straggling scratches turning to S. 60° W. On the mountain road ascending to Beach's Mountain House, about half-way up its long grade, the scratches run S. 25° W., parallel to the mountain face. On the new road leading from the Kaaterskill Hotel eastward across the plateau to South Mountain, the freshly uncovered sandstone ledges show very distinct *Stossseiten*, indicating an ice-overflow from the Hudson valley across the mountain and up the Palenville clove; the directions of ice-motion, here clearly determined by the form of rock-surface and the well preserved scratches, were N. 80°, 75°, 50°, and even only 35° W., giving a westward deflection from the main valley of more than a quadrant.*

The general absence of drift over the limestone belt and the sandstones to the foot of the Catskills is noteworthy; largely on this absence depends the clearness of the topography of the region. There are no sheets or mounds of till or gravel; everywhere but in the deeper valleys the country rock comes close to the surface and appears in abundant outcrops; and the drift is recognized only in scattered stones and boulders of northern origin: in French's quarry there is, for example, a two-foot boulder of garnetiferous granite, presumably from the Adirondacks.

There is no clear evidence of any marked effect of glacial action on the topography, unless we place the little Black, Canoe, and Van Luven's lakes here; but they are small, and probably very shallow, and quite as likely the result of drift obstruction as of ice excavation: they all occur on the lower part of the grits, where these join the Upper Pentamerus, and this as we know elsewhere shows a tendency to valley form. We had not time to study the origin of the basin of Green Lake, the largest of the district.

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* This deflection has been observed by Mather, 1843, 203; Ramsay, Quart. Journ. Geol. Soc., XV., 1859, 208; and Julien, N. Y. Acad. Sci. Trans., 1881, 24–27.

The large blocks of Corniferous limestone, weathered loose along its margins, may be mentioned again here. The best examples are on the Old King's road where it joins the Mountain road; several of the blocks are eight or ten feet cube. They cannot be considered simply as glacial boulders, for they occur only along the disappearing margins of their formation; they cannot be of pre-glacial weathering, for the ice stream that filled the Hudson valley till it overflowed its mountain boundaries east and west can hardly have left any loose blocks so near where it found them. So we are forced to consider them largely the product of post-glacial weathering, mostly by solution; but this gives a so much greater measure of post-glacial erosion than is generally found, that it is not satisfactory. Some of the blocks are separated from one another and from the still continuous bed out of which they seem to have weathered, by a hundred feet or more. The limestone would therefore have to be easily dissolved by surface waters, although it is very dense physically; and yet the same limestone under the clays of the Marcellus valley, where much water must have filtered in along the contact of rock and clay, has not lost its glacial scratches. The case is not satisfactorily explained.

All the lower valleys are occupied by stratified clays capped with sands up to about one hundred and fifty feet above the Hudson (tide-water). Near the river, the area and often the depth of these clays are very great; they cover all but the higher sandstone ridges, which crop out as rocky islands. Farther back from the river, the clays fill the depressions among the limestones, as is nicely shown in the Fuyk, when viewed from the Lower Pentamerus cliff on the east; and the long valley cut on the Marcellus shale, where it is followed by the Kaaterskill and far north and south as well, is deeply buried under the clay terraces.

It is easy to see that, if the clays were stripped off, and the country elevated several hundred feet as it has been in the past, its valleys and drainage would be considerably changed from their present arrangement; but just what these changes would be is difficult to say. I think it probable, however, that the Kaaterskill would leave the Hamilton a little to one side of its present course at Big Falls; that both the Kaaterskill and the Catskill would run along the Marcellus valley at a lower level than their present beds, and would escape eastward by some channel farther south than our map extends. If this view is correct, it follows that Big Falls, like so many other cascades in New York and other glaciated States, result from an old stream's taking a new course (I believe this to be a general explanation for many falls); that the Kaaterskill now makes its way through the Little Mountains over a broadly open pass that once led from the Hudson to the Marcellus valley; that the Catskill, although larger than the Kaaterskill, was accidentally turned into a smaller cross-valley, which it has since deepened somewhat into the appearance of a gorge. Such disturbance of pre-glacial drainage is a very common occurrence in our Northern regions, and often gives rise to lakes.

Further study is needed to learn the features of the Helderberg folds as they extend northward to the south line of Albany County, where Mather (1843, 335) says they end, and to show their increase to the south.

Since writing my article for *Appalachia*, several months ago, an excursion to the mountains in Central Pennsylvania has given me new reason to repeat what was then said concerning the advantages of the Little Mountains for studying the elements of topography; for in Pennsylvania the structural features are on so much vaster a scale, that days are there required for what can be seen much more clearly in a few hours near Catskill.

This article is accompanied by two plates, numbered XII. and XIII.

Plate XII. contains sixteen figures, described in the text.

Plate XIII. is a colored map showing the district here described.

CAMBRIDGE, January 15, 1883.

Fig 1

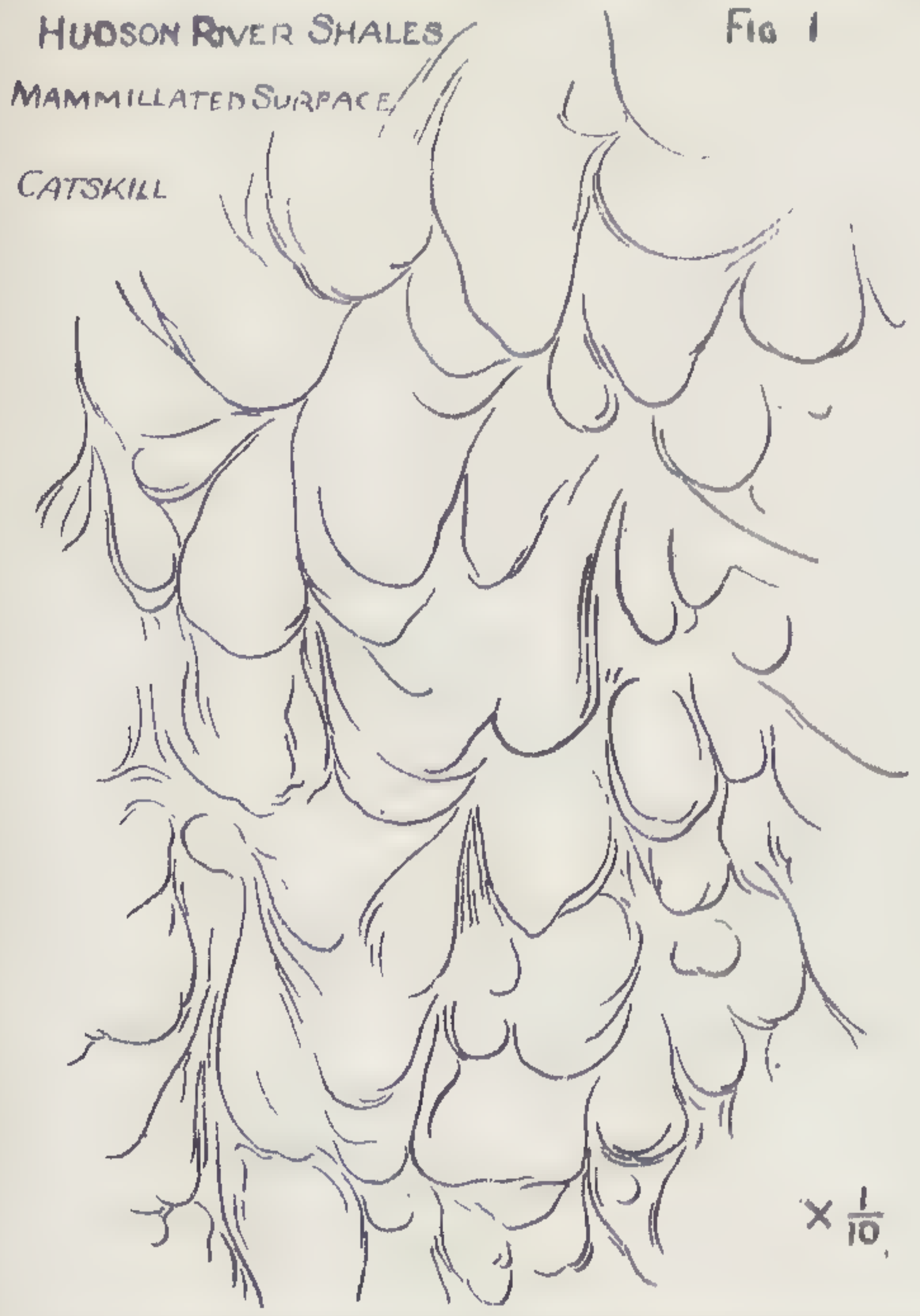
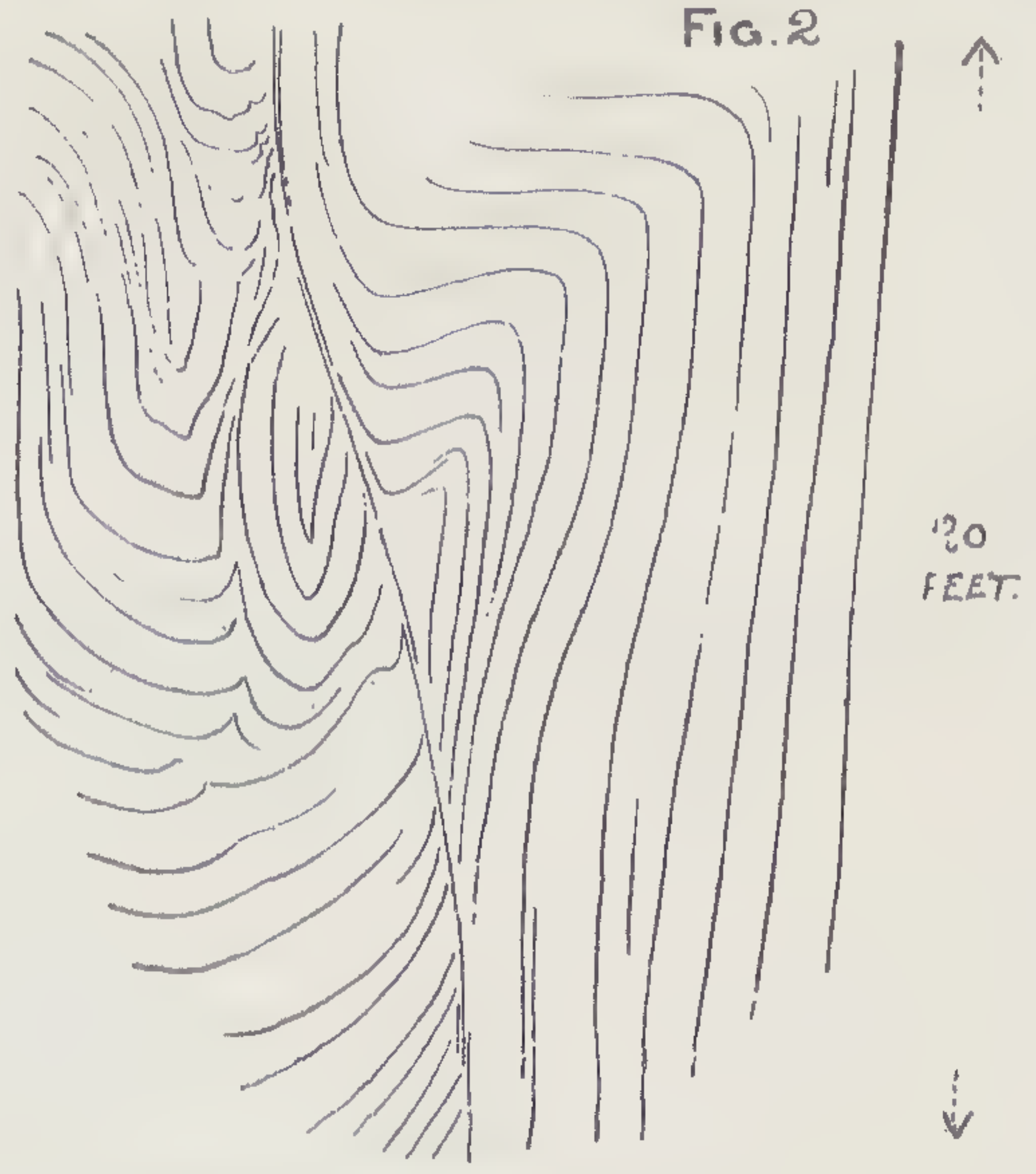

Hudson River Shales
Mammillated Surface
Catskill
× 1/10

Fig. 2



Contorted Hudson River Shales
R.R. Cut, Catskill.

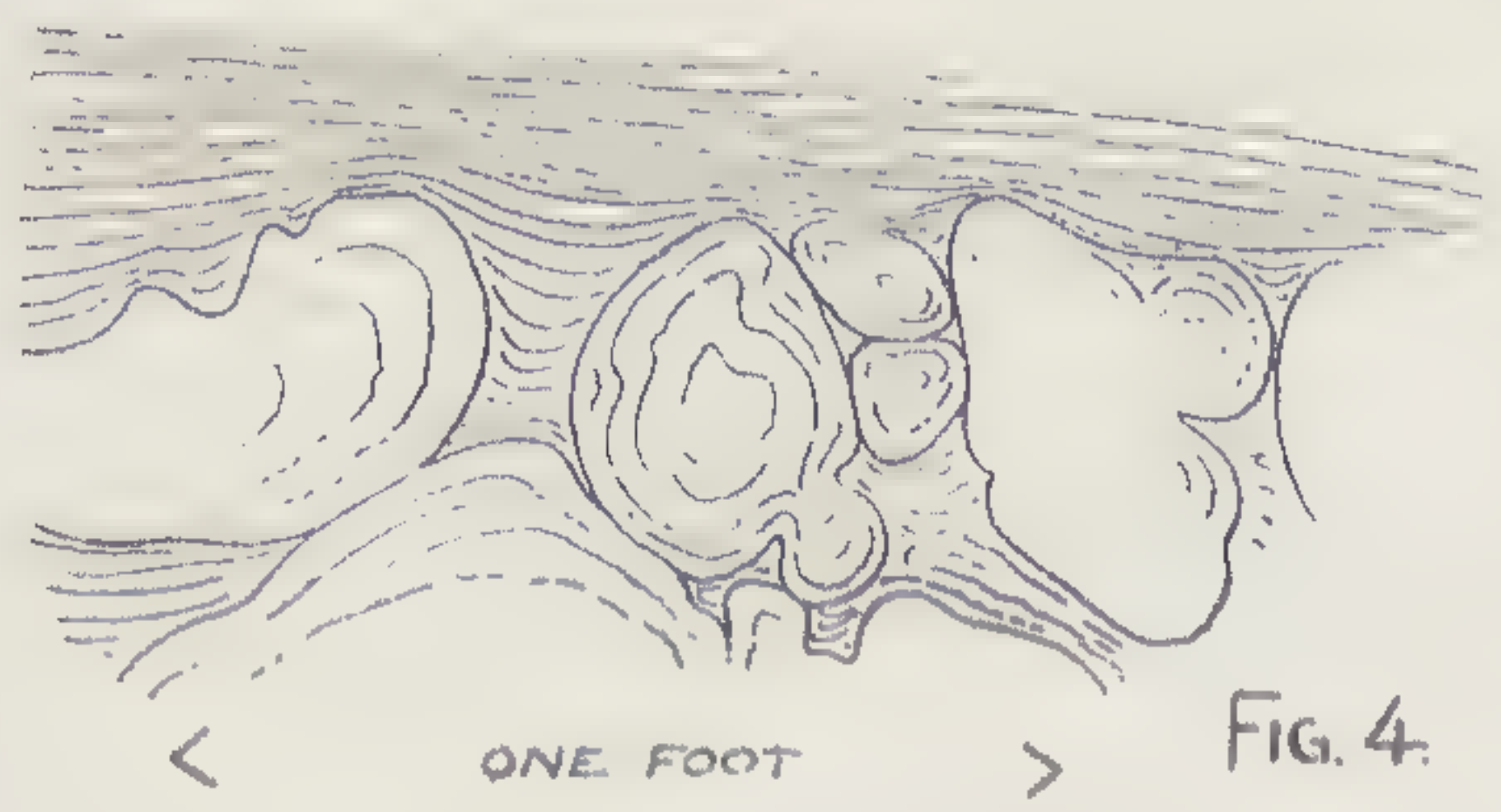
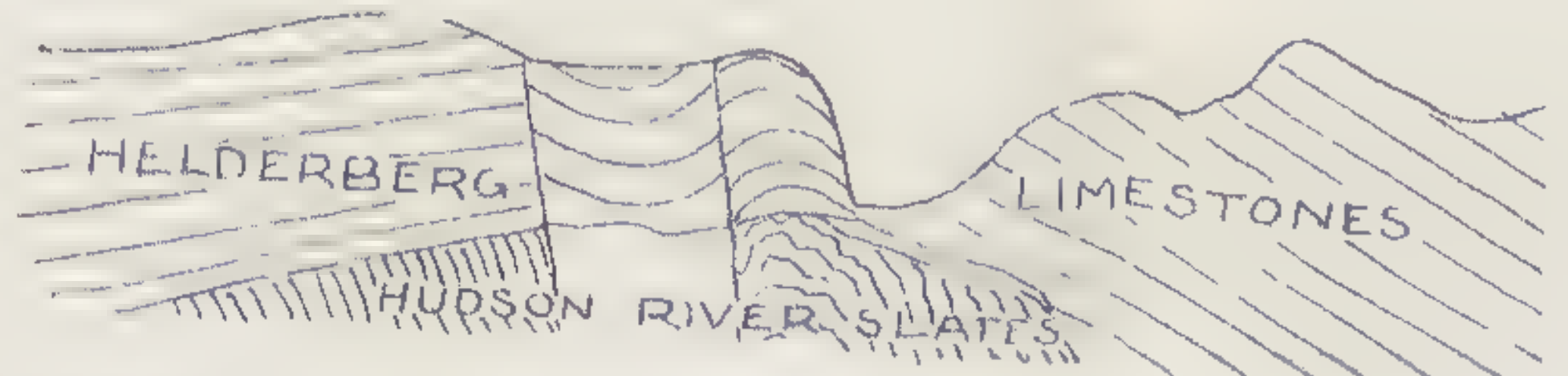


Fig. 4.

Fig. 6

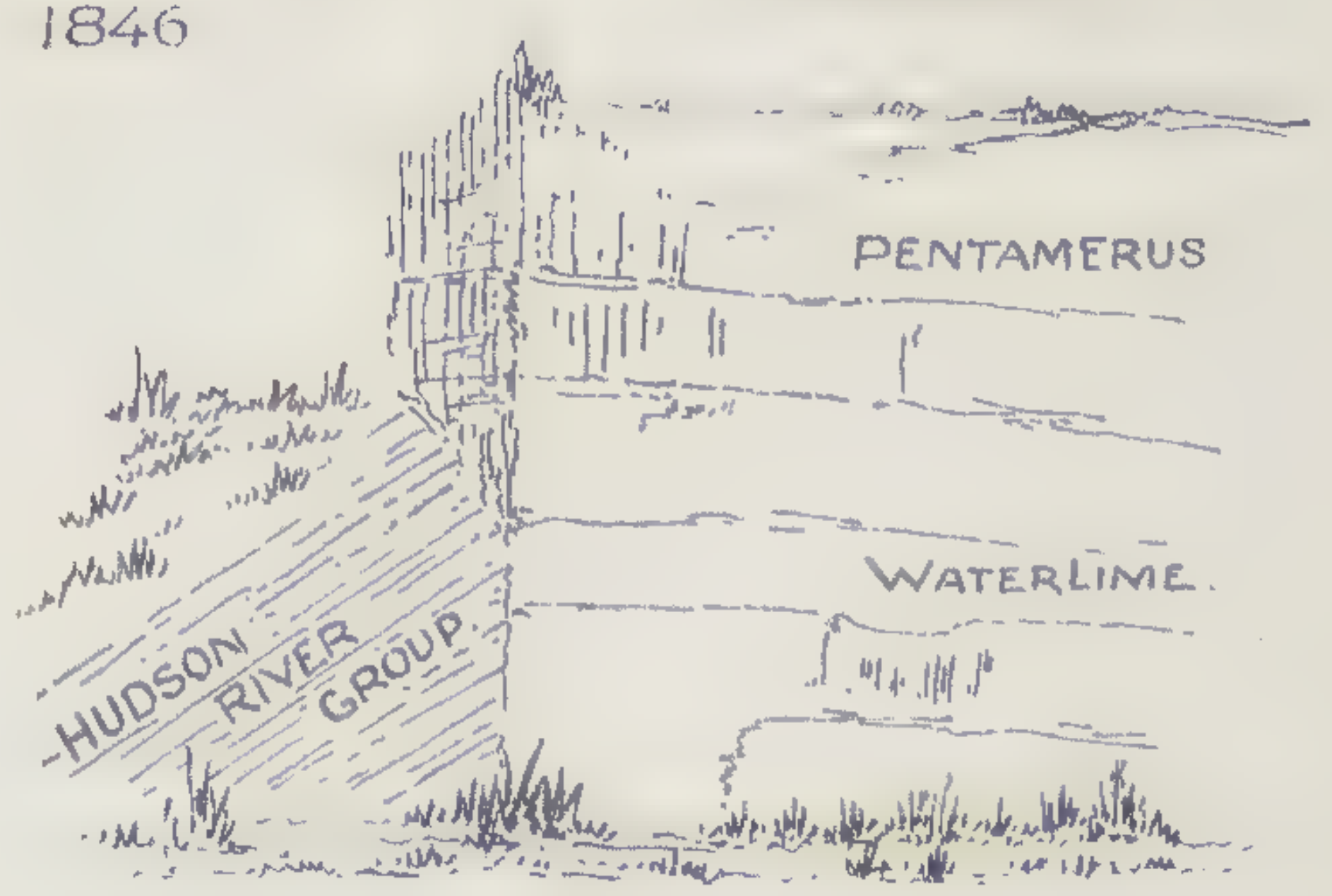

Helderberg
Limestones
Hudson River Slates

Mather, 1843.
Pl. 26, fig. 1.

Rondout,
opp. Wilbur.

Fig. 14
Emmons
1846

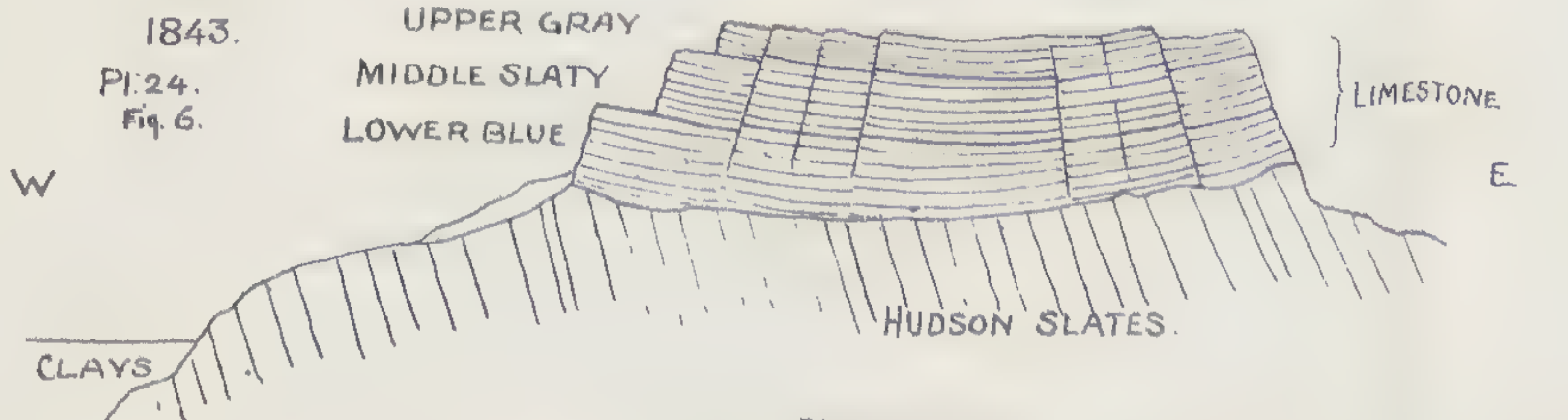
At the Cement Quarries,
Kingston, N.Y.


Pentamerus
Waterlime.
Hudson River Group

Mather
1843.
Pl. 24.
Fig. 6.

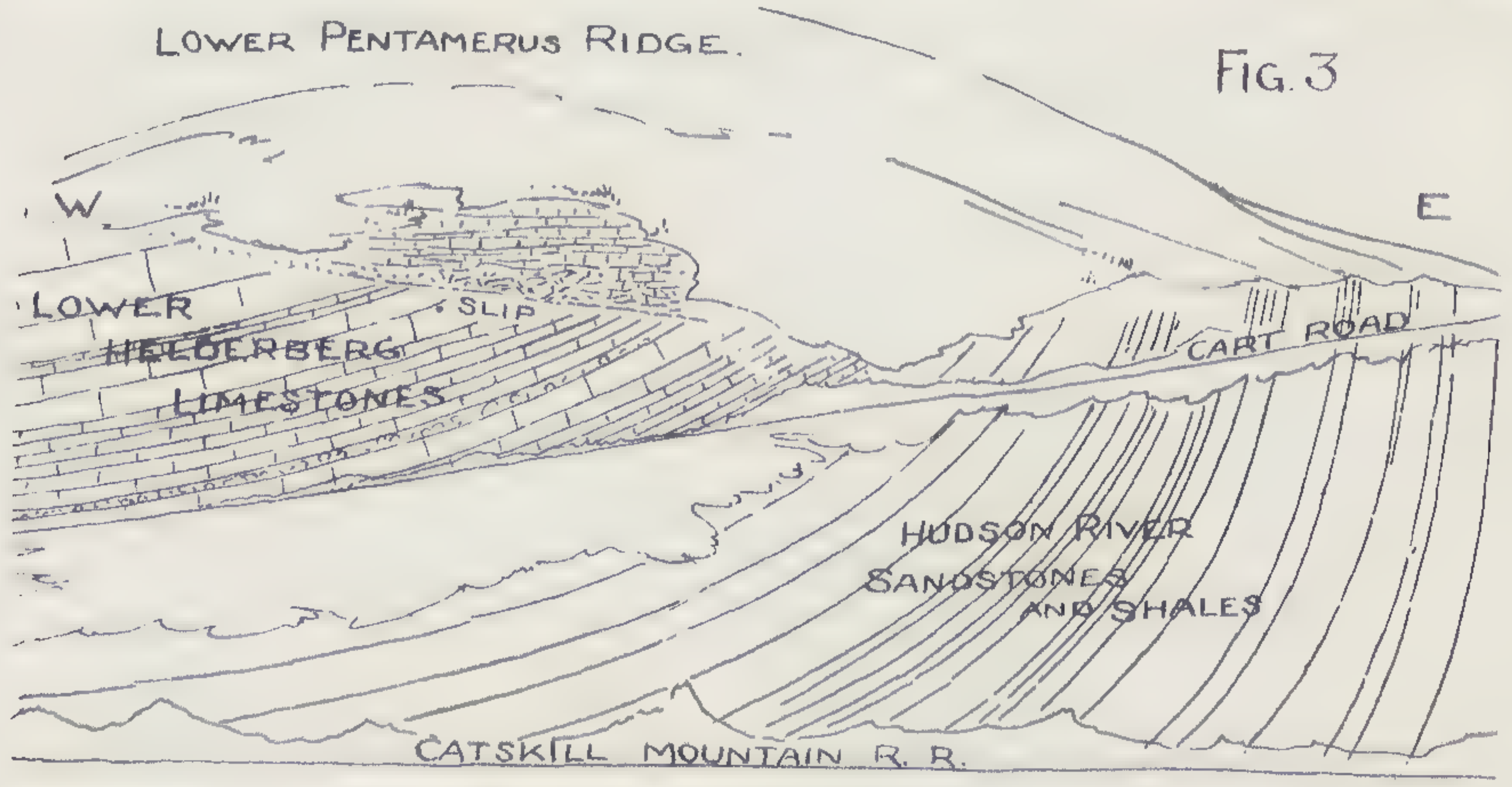
Becraft's Mountain

Fig. 7.


Upper Gray
Middle Slaty
Lower Blue
Limestone.
W
E.
Clays
Hudson Slates.

Lower Pentamerus Ridge.

Fig. 3

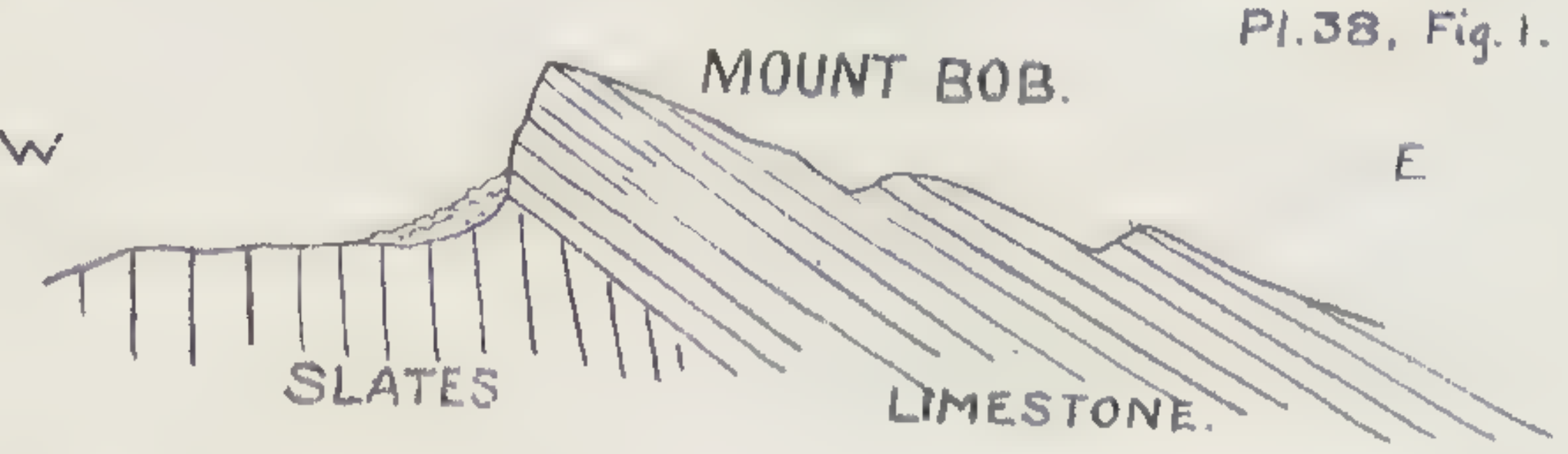

W.
E
Lower
Helderberg
Limestones
Slip
Cart Road
Hudson River
Sandstones
and Shales
Catskill Mountain R. R.

The Catskill. →

Section below Austin's Mill

Fig. 8.

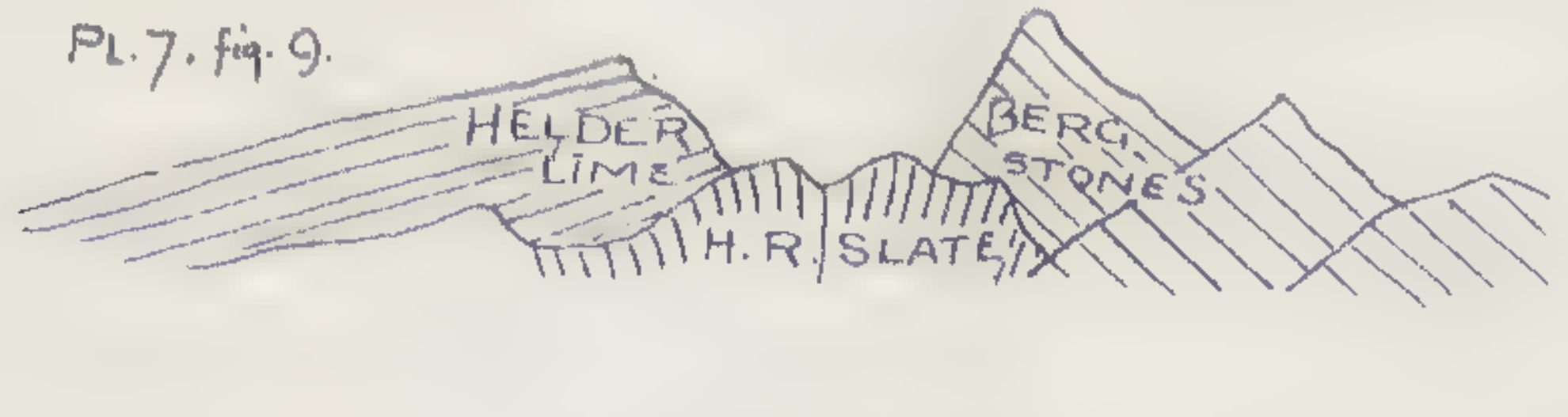
Mather.
Pl. 38, Fig. 1.


Mount Bob.
W
E
Slates
Limestone.

Mather, 1843.
Pl. 7. fig. 9.

Fig 9

Esopus Cr.


Helder
Lime
Berg
Stones
H. R. Slates

Dale, 1879.

Helderberg.
Limestones.
on
Hudson River
Slates,
Rondout

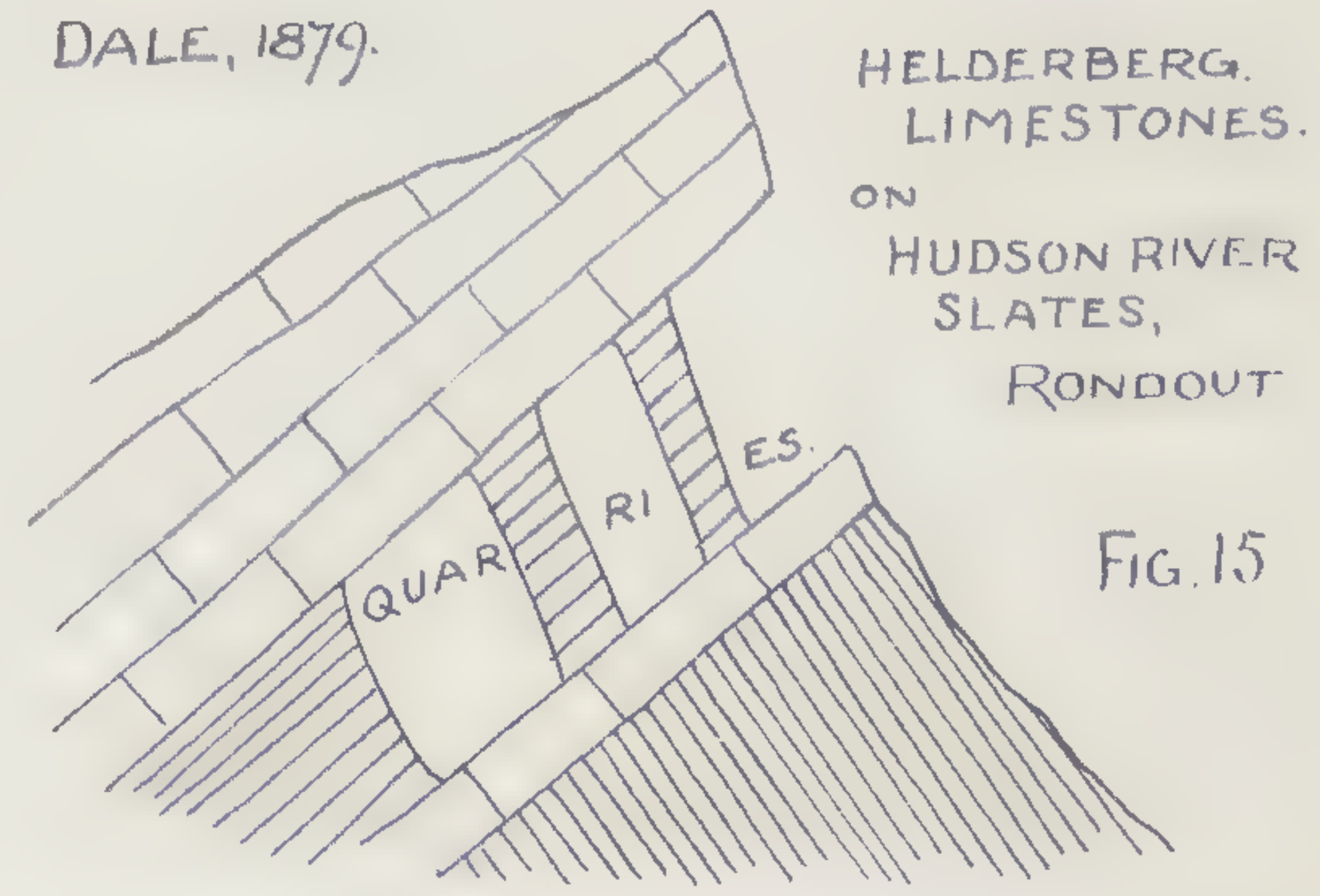
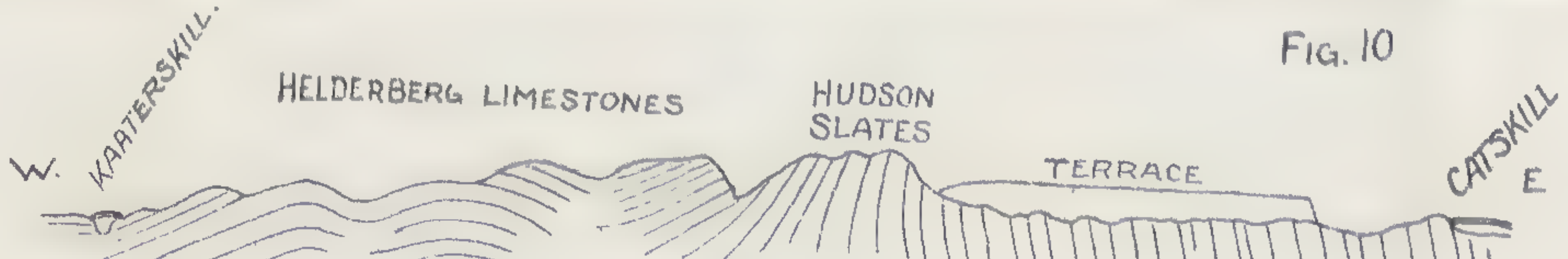


Fig. 15

Fig. 10


W.
Kaaterskill.
Helderberg Limestones
Hudson
Slates
Terrace
Catskill
E

Mather. 1843

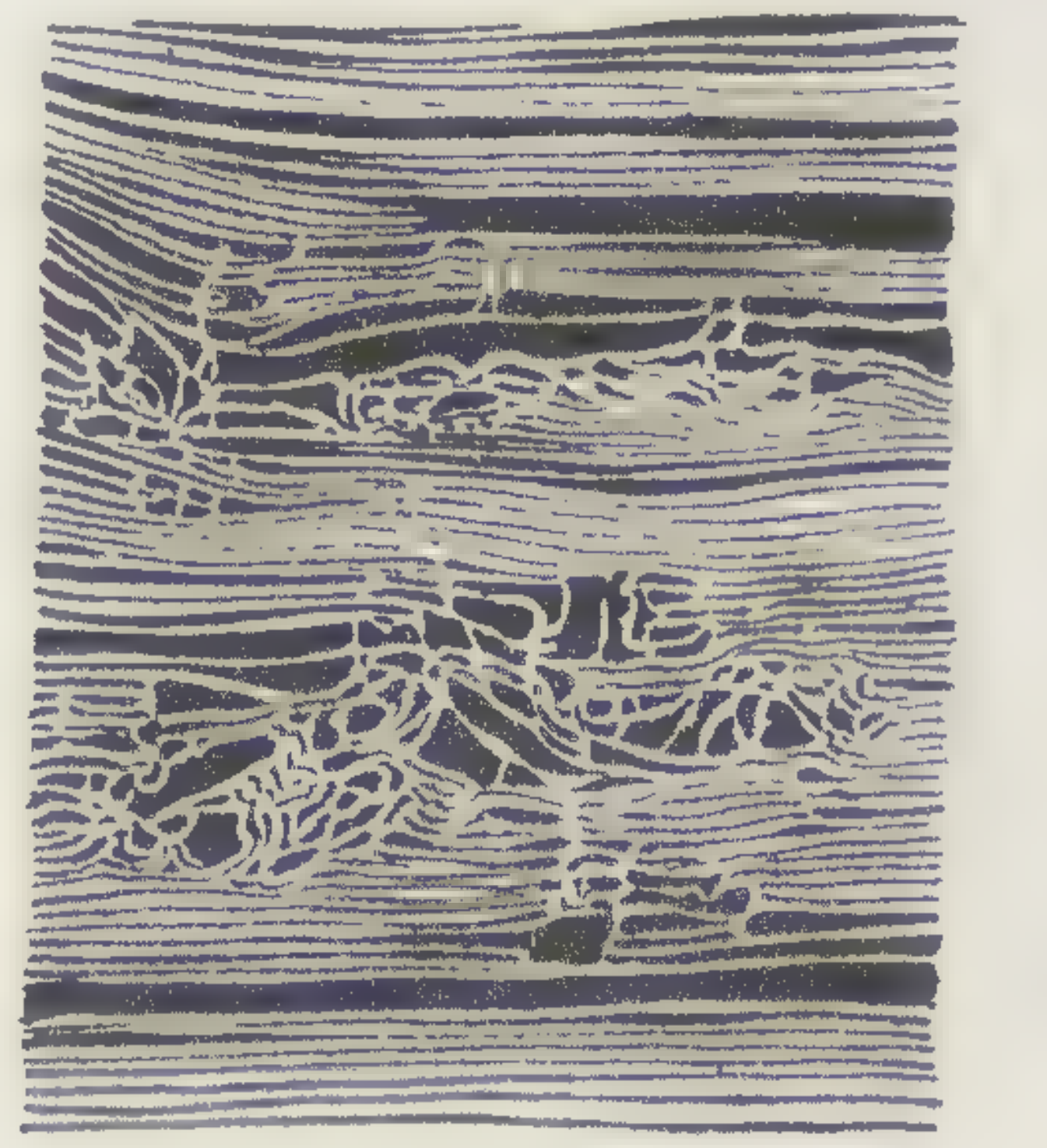
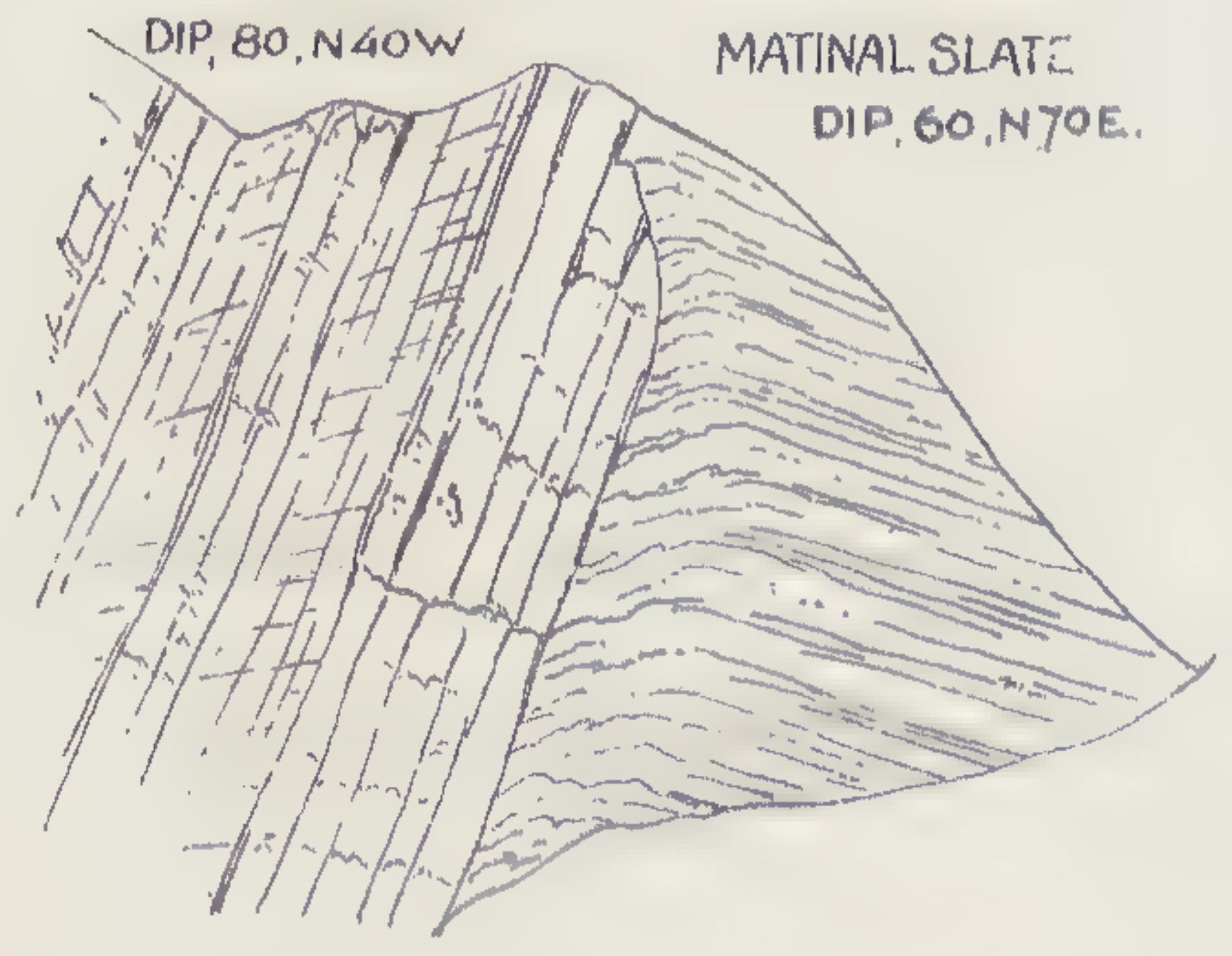


Fig 16.

Pre-Meridian
Limestone.
Dip. 80, N40W

Fig. 11.

Matinal Slate
Dip. 60, N70E.

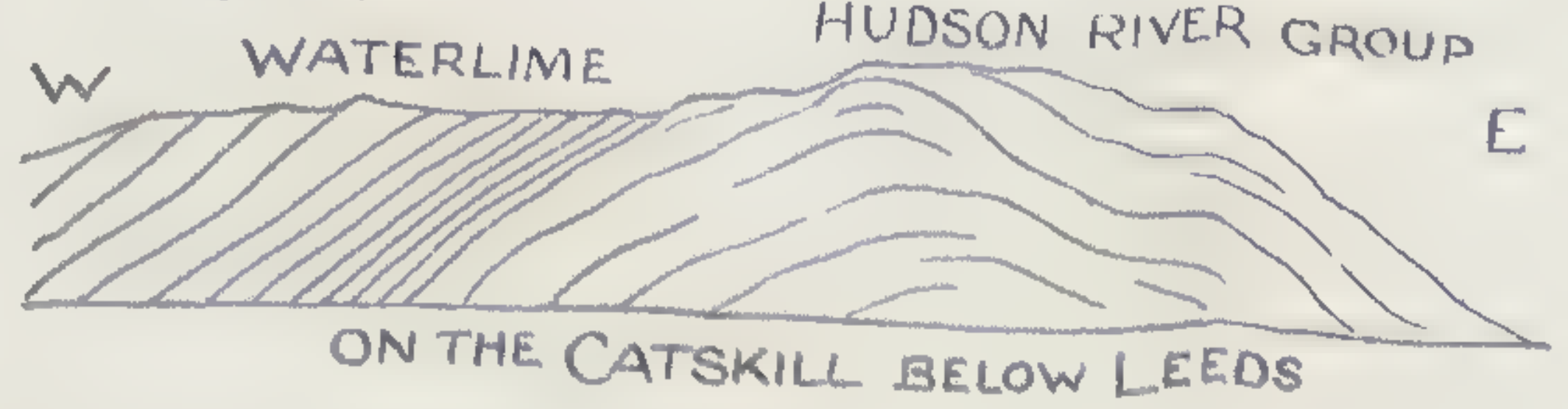


Hasbruck's Quarry
Rondout, N.Y.

H. D. Rogers. 1858. ii. 785.

Emmons 1846.
Sec. 5. pl. xx

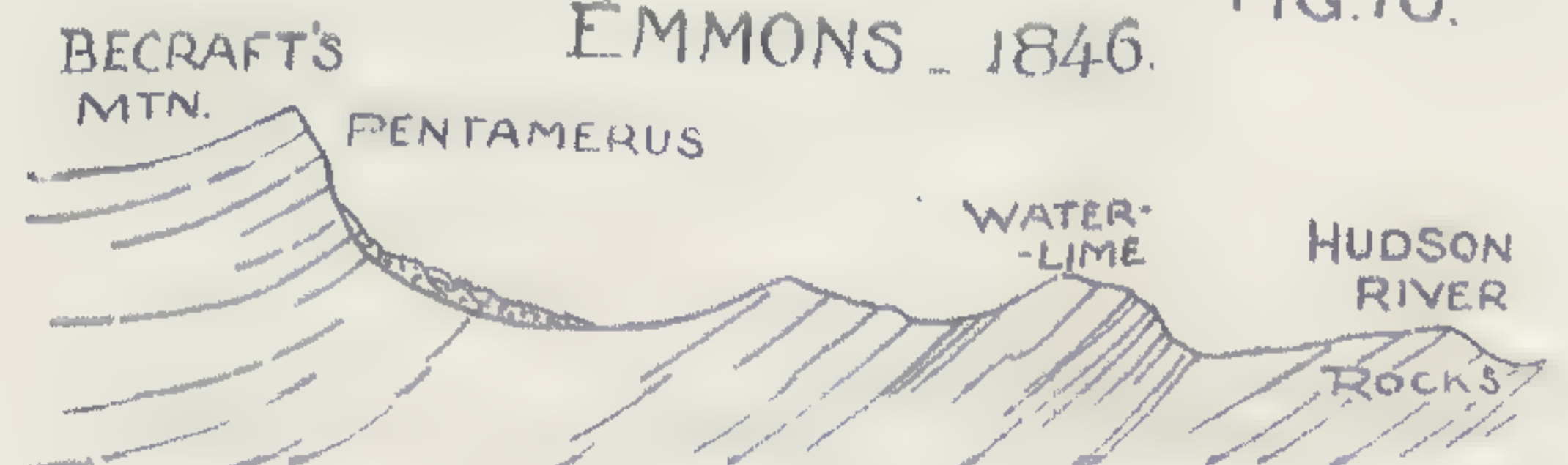
Fig 12


W
Waterlime
Hudson River Group
E

On the Catskill below Leeds

Emmons _ 1846.

Fig. 13.


Becraft's
Mtn.
Pentamerus
Water-
-lime
Hudson
River
Rocks

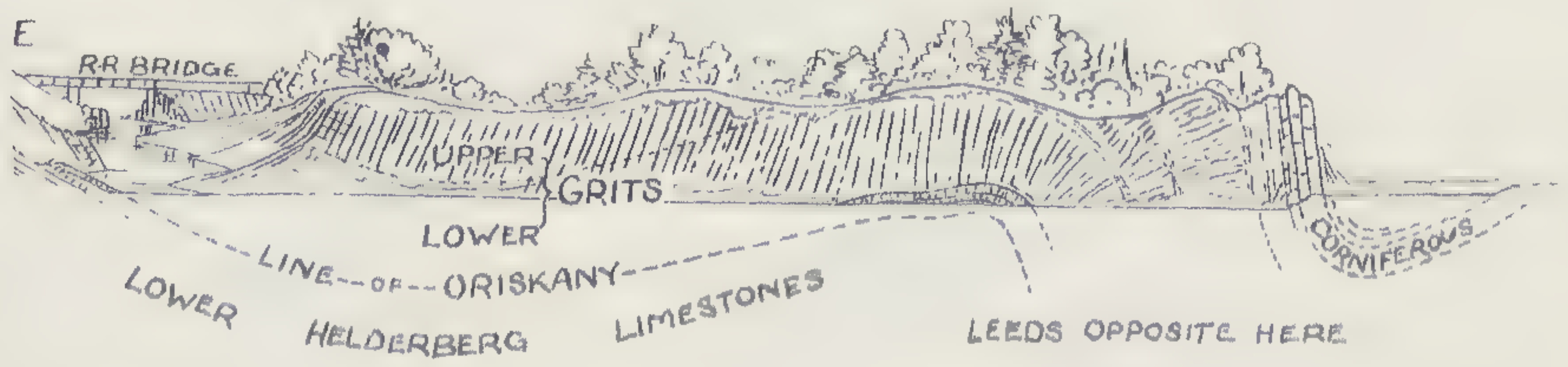

E
RR Bridge
Upper
Grits
Lower
Line of Oriskany
Corniferous
Lower
Helderberg
Limestones
Leeds opposite here

Fig. 5. Right bank of the Catskill at Leeds

Diagrams
of
The Helderberg Rocks
in and near
Green County, N.Y.
from various authors & original drawings
by
W. M. Davis.
1882

The Heliotype Printing Co. 211

BIG FALLS
SOUTHERN ANTICLINAL VALLEY
SAW MILL
OLD KINGS ROAD
VAN LUVEN LAKE
STREEKE
SINK HOLE
FOUNTAIN
TO PALENSVILLE
LIME KILNS
SINK HOLE
MOUNTAIN
LONG SHANK
KALK BERG
WEST BERG
THE FUYK
ROAD
QUARRY
SAW MILL
HOOGE BERG
KAATERSKILL
KAATERSKILL FALLS
TO CATSKILL
WEST SHORE RAILROAD
CATSKILL
VAN VECHTEN FLATS
CATSKILL MOUNTAIN R. R.
LIME KILNS
AUSTINS MILL
SUSQUEHANNA
TOLLGATE
LEEDS
TURNPIKE
BLOCKS MILL
KALK BERG
VOSEN KILL
LUYSTER BERG
CANOE L.
BLACK LAKE
GREENS LAKE
XV
XIV
XIII
XII
XI
X
IX
VIII
VII
VI
V
IV
III
II
I
Catskill Shaly.
Lower Pentamerus.
Tentaculite. Waterline.
Hudson River.
Terrace Drift.
Corniferous.
Cauda Galli Grits.
Upper Pentamerus.
One Mile.

THE
FOLDED HELDERBERG LIMESTONES
IN
GREEN COUNTY, N.Y.

W. M. DAVIS.
1882.

Bulletin of the Museum of Comparative Zoölogy,
AT HARVARD COLLEGE.
WHOLE SERIES, VOL. VII.
(GEOLOGICAL SERIES, VOL. I.)

No. XI.

THE
AZOIC SYSTEM
AND ITS PROPOSED SUBDIVISIONS.

BY

J. D. WHITNEY AND M. E. WADSWORTH.

CAMBRIDGE:
PRINTED FOR THE MUSEUM.
AUGUST, 1884.

TABLE OF CONTENTS.

PART I.

SYNOPSIS OF THE EVIDENCE ON WHICH THE ROCKS OF THE AZOIC SYSTEM HAVE BEEN VARIOUSLY GROUPED INTO DISTINCT DIVISIONS BY AMERICAN GEOLOGISTS.

CANADA.

The "Metamorphic Series" of LOGAN, as defined by him in the Report of 1845–46, 331; his two divisions of the same, based only on theory, 332; his description of the Metamorphic Series on the north shore of Lake Superior, in the Report of 1846–47, 333; HUNT'S subsequent misrepresentation of Logan's views, 334. MURRAY'S description of the formations of the Kamanistiquia Basin, 334; the two series of rocks subsequently known as the Laurentian and Huronian shown by him to be conformable, and to pass imperceptibly into each other, 334; this fact not mentioned by HUNT in his account of Murray's Report, 334. MURRAY'S description of the rocks on the north shore of Lake Huron, Report of 1847–48, 335. LOGAN'S description of the same, in 1848, 335, 336; he confuses the Azoic rocks of Lake Huron with the Palæozoic of the south shore of Lake Superior, 336; HOUGHTON'S views misrepresented by Logan, 336. MURRAY, in Report for 1848–49, again describes region north of Lake Huron, 337. LOGAN, in 1852, calls these rocks Cambrian, 337. In the Report for 1852–53, published in 1854, LOGAN gives the name "Laurentian" to the rocks previously designated by him as "Metamorphic" or Cambrian, this name being the equivalent of the term Azoic, previously introduced by FOSTER and WHITNEY, 337, 338; the term "Huronian" first used, by HUNT, in 1855, 338; the Huronian said by him to be unconformable with the Laurentian, 338; this an error, based on the confounding, by Logan, of the Azoic of Lake Huron with the Palæozoic of Lake Superior, 338. First mention of the Huronian in the Canada Reports, 338, 339. The relations of the Laurentian and Huronian indicated in Report for 1856, 339; relation of the hypersthene rock, since called "Norian," indicated by HUNT, 1855, and again in 1856, 339. Division of the Azoic into Laurentian and Huronian, and the name Laurentian opposed, and LOGAN'S entire misconception of the geology of Lake Huron and Lake Superior pointed out by WHITNEY, in 1857, 340; LOGAN recognizes his mistake, but does not abandon the terms introduced by him, 340; further statements of LOGAN (1857) in regard to the Laurentian and Huronian, 340, 341; peculiar logic of his statements indicated, 341. Bigsby points out that the Huronian is distinct from the Cambrian and conformable with the Laurentian, 341, 342. Logan's statement, in the Report for 1863, that the Laurentian rocks had been shown by the Canada Survey to be metamorphic sedimentary, controverted, 342. The relation of position of the Laurentian and the Huronian discussed, 343, 344. In the Report for 1863, Logan abandons the idea that the copper-bearing rocks of Lake Huron and those of the south shore of Lake Superior are of the same age, 344. Hunt's views, set forth in the same Report, as to the sedimentary character of the labradorite rocks in the Laurentian, 344. Macfarlane, in the Report for 1863–66, describes the contact of some supposed Huronian with the Laurentian, on north shore of Lake Superior, near Michipicoten Island, 345 ; his observations show that both formations are eruptive, and of the same age, 346. Hunt, in Paris Exhibition Report of 1867, claims that the Laurentian comprises two distinct sets of rocks, unconformable with each other, 346. Richardson, in Report for 1866–69, on the Laurentian of the Lower St. Lawrence River, 346. Marcou says that the Laurentian is a mixture of the Upper Taçonic with the "Triassic of Lake Superior," 347. Bell, in the Reports for 1871–72 and 1872–73, points out the conformability of the Huronian and Laurentian in the region northwest of Lake Superior, 347, 348 ; Selwyn thinks this apparent conformity only local, and that there is really a very considerable break between the two formations, 348. Selwyn's views shown to have no basis of fact, 348. G. M. Dawson's and Bell's observations in the same region, 349 ; their views criticised and commented on, 349. Bell, in the Report for 1877–78, shows that the Laurentian and Huronian are conformable in the Hudson's Bay region, 349, 350.

First mention of the Hastings series, by Murray, in Report of 1852–53, 350 ; the same discussed by Macfarlane, in Report of 1866, also by Logan, who says that it is conformable with the Laurentian, 350 ; Hunt says that the Hastings series is overlain unconformably by the Upper Laurentian, 350. Vennor gives two entirely different sections of the Hastings series in 1867, and in the Report for 1866–69, 351 ; his views as to the relations of this series to the Laurentian and Huronian, 352–354. Hunt, in 1869, refers the Hastings series to the Laurentian, 350 ; in 1870, to the Terranovan, this being regarded as in part Potsdam, 354, 355 ; Hunt, in 1871, says that the Hastings series is conformable with the Laurentian, 355 ; later in the same year, that it is not, 355 ; in 1875, he says that the Montalban or Hastings series occupies a position between the Laurentian and the Trenton, 356 ; in 1878, he refers the Hastings series to the Lower Taconic, and misstates the views of Logan and Bell in regard to its conformability with the Laurentian, 356. Selwyn announces very different views from those of Hunt, and shows up something of the prevailing confusion in Canadian geology, 356–359. Macfarlane, 1879, objects to Selwyn's views, 359 ; J. W. Dawson asserts his disbelief in the results of the Canada Survey, as bearing on the age of the Hastings series, 359.

NEW BRUNSWICK.

J. W. Dawson, in 1855, refers the rocks in the vicinity of St. John to the Lower Carboniferous, and in 1861 to the Devonian, 360 ; Matthew divides the same rocks into six groups, and refers to Devonian, Silurian, Laurentian, and Huronian, 360–362. Bailey, Matthew, and Hartt, in 1865, give their views of the age of the rocks of Southern New Brunswick, 362, 363. Bailey and Matthew again, in the Report for 1870–71, express their opinions of the sequence of these rocks, 364; numerous changes made, to conform with the views of Hunt based on lithological considerations, 364; confusion thus introduced, 364–366; faults and overturns imagined in order to sustain these new views, 367; an easy explanation of the difficulties, 367. Further confusion and shifting of the various groups from place to place by Matthew and Bailey, in the Reports for 1876–77 and 1876–78. Ells, in the Report for 1876–78, describes rocks as Laurentian and Devonian, which in 1865 were called Devonian, and in 1871 Huronian. Further changes, and the St. John group placed in the Cambrian, in the Report of 1878–79, by Matthew, Bailey, and Ells, 368. Bailey's view of New Brunswick geology, in 1880, 368, 369. Hunt, in 1878, presents his views of New Brunswick geology, mingling his own ideas with those of Bailey and Matthew, and disregarding the sequence of time in which these were presented, 371; resulting confusion, 371; impossibility of harmonizing Hunt's views, as expressed in 1870, with his subsequent explanation of them, 372; a tabular statement of Hunt's views as expressed by him in 1870, and as that expression was explained by him afterwards, 372; remarks on the value of the work thus done, 372. Matthew and Bailey misrepresented by Hunt in 1879, 373. The rocks of Southern New Brunswick declared by Hunt, in 1875, to be Huronian and Montalban, 373. Various views of the New Brunswick geologists, so far as the same can be deciphered, presented in tabular form, 374.

NOVA SCOTIA.

Hind, in 1870, indicates the presence of Huronian and Laurentian in Nova Scotia, 374, 375; J. W. Dawson regards the Laurentian gneiss of Hind as being intrusive granite, 375; Selwyn differs from Dawson, 375; Selwyn's views criticised, 375; Hunt considers the Huronian of Hind to be Montalban, 376; Honeyman's views, which seem to be valueless, and are objected to by J. W. Dawson, 376; Hartley's opinions of rocks of Cape Breton, and some suggestions in regard to them, 376; Robb's examination of the same region, in the Reports for 1873–74 and 1874–75, 376; Selwyn's commentaries on Robb's work, 377; great change in Selwyn's views since 1871, 377. Further statements by J. W. Dawson, in 1878, 377. The condition of the question summed up, 378.

NEWFOUNDLAND.

Reconnaissance by Jukes, in 1839–40, 378. Murray, in the Report for 1864, recognizes the Laurentian, and gives a table of the formation occurring in Newfoundland, 379. In the Report for 1868, Murray introduces an Intermediate system, supposed to be the equivalent of the Cambrian and Huronian, 379; supposed fossils in this series, 379; these rejected by the palæontologist of the Survey, 379; further discoveries of supposed fossils in these rocks, 380; Murray, in the Report for 1873, presents reasons for dividing the Laurentian into two groups, 380; the real state of the case, 380.

LABRADOR.

Packard's observations in 1865; he recognizes there, on very inadequate evidence, the Laurentian and Huronian, 381; labradorite rocks seen, apparently eruptive, but called by him Norian, 381; Hind refers the rocks of Labrador to the Laurentian on lithological grounds, 381; Wilkins holds the same views, calling a dike Norian, 382.

MAINE.

Geological Survey under C. H. Hitchcock developed nothing of value in regard to the Azoic rocks, 382; Hunt infers that the mica schists and gneisses of Maine are of Montalban age, and that the rocks near Portland are Huronian, and older than the gneisses, 382; C. H. Hitchcock holds exactly the opposite view, 382. No evidence whatever in regard to the age of the crystalline rocks in Maine other than lithological, 383.

NEW HAMPSHIRE.

Hunt, in 1847-48, in 1863, and again in 1867, refers the rocks of the White Mountains to the Devonian, 384; Lesley does the same, and claims for the range a synclinal structure, 384; his probable error, 384; Hunt, in 1878, says that Logan considered the White Mountains as Devonian, omitting to state the fact that he himself had repeatedly published the same opinion, 384; Hunt, in 1870, called the White Mountains Terranovan, which he considered as being in part of Potsdam age, 384. C. H. Hitchcock's first scheme of the rocks of New Hampshire, in the Report of 1869, in which most of them are referred to the Quebec group, 385; another arrangement, in the Second Report, for 1870, 385, 386; in the Third Report, 1870, the White Mountains are called Eozoic, which "satisfactory reference" is said to "clear up the obscurities of New Hampshire geology," 386; further changes, in Report for 1871, and introduction of the Norian, "the prevalent opinion in regard to the age of the New England metamorphic rocks must be changed to conform to the discovery of labradorite in our State," 387; Hawes, however, regards the labradorite rock as eruptive, 387; Hunt, in 1873, accepts the Norian; but, in 1878, says that it is found to be of eruptive origin, 388; C. H. Hitchcock, in 1872, endeavors to prove that the Norian rocks are of sedimentary origin, 388; further remarks to the same effect by C. H. Hitchcock, in various papers published in 1871-72, 389; also, in Final Report, Vol. II., in which we are told that "the facts as interpreted [in reference to the Norian or Labrador system] are of great consequence, since they fix the geological horizon of the whole Atlantic system," 389, 390; later on in the same volume, all that had been said of the Labrador system taken back, the rocks recognized as being eruptive, and the exposures on Mt. Washington formerly considered as stratified now called "injected dykes," 390. C. H. Hitchcock, in the Report for 1872, assigns the Quebec group to the Huronian, the Concord granite said to be sedimentary, 391; the same author presents, in the Report for 1872, a classification of the rocks of New Hampshire (see Table), 391, 392; "granite flowed over the country like water," 392; "ten distinct periods traced on the scarred sides of the White Mountains," 392;

C. H. Hitchcock demonstrates the importance of mineral characters in the classification and identification of rocks, 393; the rocks of New Hampshire classified on that basis, 393; Hunt called on by C. H. Hitchcock to decide which way the porphyritic gneisses dip, 394; Huntington points out facts indicating that the Concord granite is intrusive, 394; C. H. Hitchcock states his views in Final Report, Vol. II., in regard to the importance of not "obscuring observations" by "individual speculations," 394, 395; some results of investigations made to ascertain how far C. H. Hitchcock was able to distinguish and properly name rocks, 395–397; authenticity of specimens examined by us, 397; notice of our tabular view of the classifications presented at various times by the New Hampshire Survey, under C. H. Hitchcock, 397, 398.

EASTERN MASSACHUSETTS.

S. Godon's observations in 1807–8, 398; his division of the formations in the vicinity of Boston, 398–400; Maclure's geological map, 400; error of Hunt in describing Maclure's work, 400; J. F. and S. L. Dana's contribution to the geology and mineralogy of the region near Boston (1818), 401, 402; Eaton's Index to the Geology of the Northern States, 402; Thomas Cooper, 1822, recognizes the volcanic character of some of the rocks near Boston, 403; Hitchcock's first publication (1824) in regard to geology of Eastern Massachusetts, 403; Hitchcock contributes to the geology of the same region in Eaton's Survey of the Erie Canal, 403, 404. J. W. Webster, 1824–25, publishes Remarks on the Geology of Boston and its Vicinity, 404. Hitchcock's Report, 1833, and his theoretical views as set forth in that volume, 405–409; his final report, 1841, 409, 410; his theories set forth and commented on, 410. Prescott's geological investigations in Essex County 839), 410.

Hunt, in 1854, refers the limestones of Eastern Massachusetts to the Devonian, 411; he states, in 1861, that he recognizes in New England or Southeastern Canada "nothing lower than the Silurian," 411. Discovery of fossils near Boston, and recognition of the locality from which they came, 411; various statements as to the dip of the rocks from which these fossils came, 411, 412; Hunt, in 1866, on the limestones of Eastern Massachusetts, considering it doubtful whether they may not be Laurentian, 412; C. H. Hitchcock, 1867, considers the gneiss and hornblende schist of Andover to "belong to the Eozoic ages," 412; his reported facts doubted, 412. Hunt, in 1869, describes the granite of New England as being a sedimentary rock, and containing traces of fossils; in 1870 he says that the granites of Cape Ann and Quincy are "probably intrusive"; in 1873, that the granites of Rockport are "distinctly eruptive," 413; necessary physical conditions resulting from Hunt's theories, 413; Bicknell finds Eozoön in limestone at Newbury, 413, 414; Hunt considers this proof of the Laurentian age of these rocks, 414.

Shaler, in 1869, considers the stratified origin of the syenites of Eastern Massachusetts clearly proved, — the syenite being seen to pass into "unquestionably sedimentary rock," 414; his geological observations shown to be incorrect, 414. Hunt, in 1870, considers the finding of the Eozoön at Chelmsford, and its identification by Dawson, as proof of the Laurentian age of the limestones of that region, 415; Hunt, in 1870, refers the gneiss of Eastern Massachusetts to the

Laurentian, and the diorites and porphyries to the Cambrian, which he then considered the equivalent of the Huronian, 416; he also says that the presence of the Eozoön "can no longer serve to identify the Laurentian system, 416; Hunt, in 1870, further discusses the geology of Eastern Massachusetts, 416, 417; comments on the views there expressed, 417, 418. C. H. Hitchcock, in 1871, publishes a geological description of Massachusetts, 418; some of his errors pointed out, 418. Hunt, 1871, refers the felsites of Eastern Massachusetts to the "great Huronian system," 418.

Hyatt, in 1871, considers the porphyries of Lynn and vicinity to be metamorphic sedimentary rocks, 418, 419; Hunt, in 1871, takes a similar view, referring these porphyries to the Huronian, and "the limestones, with Eozoön from Eastern Massachusetts," to the Laurentian, 419; some comments on Hunt's method of misrepresenting statements previously made by himself, 419, 420; Hunt again, in 1871, holds that the gneisses and limestones of Eastern Massachusetts are Laurentian, 420. Dodge's classification of the rocks near Boston, 420, 421. Bouvé, in 1876, considers the felsites to be derived from the metamorphosis of the conglomerates, 422; these views supported by Hyatt, 422, 423. Crosby, in 1876, divides the "Eozoic rocks" of Massachusetts into Norian, Huronian, and Mont Alban, considering these divisions "as both lithological and chronological," 423; the same statement affirmed in 1880, 423, 424; extraordinary nature of the views here advocated, 424; errors in Crosby's determinations of the rocks, 424. Crosby maintains that granites are derived from sedimentary rocks, 424; his mistakes as to the real character of the Rockport granite, 425; he considers the felsites near Boston to be of sedimentary origin, 426, 427; his ideas in regard to the Huronian, 427; in regard to the argillite and conglomerate near Boston, 428. Wadsworth's investigations, in 1877, of the dikes near Boston, 428; in 1878, of the Rockport granite, 428. Crosby, in 1879, advocates the theory that the felsites are of deep-sea origin, or made of the red clay deposited at the bottom of the ocean, 428, 429. Wadsworth studies, in 1878–79, these felsites, in the field and microscopically, and makes them out to be old lavas, 429; the felsites seen by him in the form of dikes, 429. Diller, in 1880, makes an exhaustive investigation of the felsites north of Boston, and confirms in all respects Wadsworth's views, 430, 431; his field of work and collections carefully examined by the authors of the present paper, and the accuracy of his results testified to, 431. Crosby, in 1880, designates what he previously had called the "Norian" as the "Naugus Head series"; this he considers the real base of the geological column in Massachusetts, 431, 432; Wadsworth finds the Naugus Head series to be of similar character to the zircon syenite of Norway; Crosby's views shown to be incorrect, 432, 433. Crosby's ideas in regard to the Huronian in Eastern Massachusetts, 433–435; his views criticised, and his reported facts shown to have, in many instances, no other basis than his own inability to distinguish between different rocks, 436.

Shaler, in 1879, maintains that the shales and conglomerates of Roxbury pass into the amygdaloidal melaphyr, 437; his theoretical deductions, made in accordance with this view, 437; Benton, in 1880, controverts these views, and shows that the melaphyr is an old, altered basalt, 437. Discussion in regard to the plasticity of the pebbles in the conglomerate, 437, 438; opposite views of Crosby and Wadsworth, 438; the spindle-shape, into which Crosby thought that the pebbles had been squeezed or pulled, shown to be only the result of his mistaking the enclosing matrix for the pebbles, 438. Dodge, in 1881, gives details of his observations near Boston, noticing the occurrence of felsite dikes in the granite, as had been before shown by Wadsworth and Diller, 439. Wadsworth, in 1881, calls attention to more of Crosby's errors of observation, 439. Wadsworth, in 1883, points out the relations of the Roxbury conglomerate to the argillite, 439. Dodge, in 1883, claims that there are two granites in the Quincy district, but offers no evidence in support of this view, 439, 440. Errors of Shaler, Rogers, and Jackson, in regard to the argillite and granite pointed out by Wadsworth, 440.

VERMONT AND WESTERN MASSACHUSETTS.

Small progress made by the earlier investigators toward unravelling the intricate problems presented in this region, 440; a specimen from Hitchcock's Final Report, 440. H. D. Rogers's division of the rocks below the "Cambrian or Older Silurian" into azoic and hypozoic, 440, 441; this classification has no basis of fact, 441; he says that it is absolutely impossible to determine "the true base of the Palæozoic system," 441. Importance to New England that the work of the Canada Survey should be well done, 441. First published statement of the bearing of the results of that survey on the solution of problems in New England geology, by Hunt, in 1849, 441, 442; the whole of the Green Mountain rocks said by him to belong to the Hudson River group, 441, 442. "With such a key to the structure of the metamorphic rocks of New England, and of the great Appalachian chain," Hunt thinks that "the difficulties that have long environed the subject are in a great degree removed, 442; similar views expressed by Hunt, in 1850, and Emmons's views of the age of the Taconic entirely rejected, 442; again, in 1854, Hunt refers the crystalline limestones of New England and their continuation southwest to the Lower Silurian, 442, 443; in 1861, and again in 1863, similar views were expressed, 443; in 1866, Hunt said that the Quebec group "constituted the great metalliferous region of Eastern Canada, Vermont, and Newfoundland"; he also refers the cupriferous rocks of Lake Superior to the same group, 443; in 1867, he repeated the same statement, considering the Quebec group as being the equivalent of the Landeilo, and further remarking that this group formed the Notre Dame and Green Mountains, and that it "played a very important *rôle* throughout the Appalachian chain," 443; this all repeated again later in the same year, 444; the statement also repeated that the White Mountains were of Devonian age, 444; again, in 1868, it is asserted that there is no proof of the existence in Vermont of any strata older than Potsdam, the gneiss of the Green Mountains being referred to the upper portion of the Quebec group, 444; once more, in 1870, Hunt asserts the lower Silurian age of the Green Mountains, 445.

In 1870, Hunt's views undergo metamorphism, and he claims that the theories which he had been advocating since 1863 were only his official ones, and that his own views were quite different, 445; the rocks of the Green Mountains begin to be called Huronian, the idea of the Devonian age of the White Mountains being abandoned, and the provisional name of Terranovan introduced for them, 446, 447; Dana objects to these views for various reasons, and especially on the ground that minerals are not fossils, and that there is no reason for assuming a chronological order in minerals, 448; in replying to Dana, Hunt asserts that he did not say that the White Mountain rocks were newer than those of the Green Mountains, 449 ; it is shown, however, that he had said this, 450, 451 ; a comparison of Hunt's statements of what he said with what he really did say, 452 ; Hunt's methods set forth, 453 ; Dana's comments on some of Hunt's statements, 453, 454, 455. Dana remarks that Hunt's volume "contains a series of misrepresentations of the views of others wholly unnecessary and difficult to find excuse for," 454 ; Dana's examination of the Helderberg rocks in the Connecticut Valley, with reference to the question whether the age of strata can be determined by means of the minerals they contain, 454, 455 ; "lithological evidence worse than worthless," 455. Selwyn's opinion of the revolution in Hunt's views, 455 ; metamorphism and mineralization no test of geological age, 455. Lesley, in 1875, states that in Pennsylvania the Huronian or Green Mountain system overlies the White Mountain series, both being older than the Potsdam, 455 ; Dana's criticism of Lesley's statements, 456 ; Lesley, in 1878, withdraws this opinion, and now considers that the Green Mountains are Palæozoic and the White Mountains Devonian, 456. Dana (1877, 1879) gives the results of his own and Wing's investigations in Vermont and Western Massachusetts, 456, 457 ; according to these, the limestones of that region are wholly Lower Silurian, and the Taconic slates overlie them, and are of the age of the Hudson River group, 457. Hunt, in 1878, further develops his views in regard to the Upper and Lower Taconic series, 457, 458. Hunt, in 1879, gives the reasons why he formerly referred the Green Mountain rocks to the Quebec group, when he in fact regarded them as Huronian, 458 ; "official reasons" not only prevented his dissenting from Logan's views, but caused him to affirm their correctness in the strongest possible manner, 458 ; further light on Hunt's methods, 458. Various contradictory statements of C. H. Hitchcock in regard to Vermont geology, 460, 461 ; in 1877 he considers the Green and the White Mountains "nearer the Laurentian than the Huronian," and in 1875 thinks that Emmons understood the relations of the rocks called by him Taconic "better than most of his contemporaries," 460, 461 ; in 1880 he finds that he had been in accord with Dana and Wing for years in their "disbelief in 'Taconism,'" 460. In 1880 and 1881, Dana brings together the evidence in regard to the geological age of the Green Mountain limestones and associated rocks, showing beyond possibility of doubt that they are Lower Silurian, 461, 462.

NEW YORK.

Geology of the Adirondacks, 462, 463 ; Hall and Logan's views in 1864, 463. Discovery of Eozoön in Westchester County, 463. Hall on the relations of the limestones of Northern New York, 463, 464. Leeds, in 1877, on the lithology of the Adirondacks, 464 ; his views criticised, 464. Britton on the geology of Richmond County, 464 ; insufficiency of his data, 465.

NEW JERSEY.

H. D. Rogers's views of the age of the gneiss and limestone of this State, 465. Cook on the Azoic rocks, 465, 466 ; some suggestions in regard to points needing further examination, 466 ; origin of the iron ores, 466.

PENNSYLVANIA.

Views of H. D. Rogers in regard to the older rocks of this State, 467, 468; remarkable contradictions in his statements, 467, 468. Hunt employed by Lesley "to collate all the known, supposed, and suspected facts of American Azoic Geology," 468; result of the same, 469. Hunt's views, in 1861 and 1871, of Pennsylvania geology, 469, 470; here again most remarkable contradictions, 470. Hunt, in 1876, makes various statements contradictory of Lesley's opinions, 471. Prime on the gneissic rocks of Lehigh County, 471; he contradicts Hunt in reference to the age of certain iron ores, 472. C. E. Hall on the formations of Eastern Pennsylvania, 472. His results differ much from those of Hunt, 473. Some remarks of Lesley in regard to the remarkable differences between the views of Rogers and C. E. Hall, 473; a key to the geology found, but "it will not turn in the lock," 474.

VIRGINIA.

Fontaine's views of the geology of the vicinity of Balcony Falls, 474. Campbell on the same rocks, 475; his peculiar views in regard to the Laurentian and Huronian, 475; criticism of these views, 476.

NORTH CAROLINA.

Kerr's report of 1875, 476, 477; he assigns a large portion of the State to the Laurentian and Huronian, 476, 477; Bradley, in 1875, considers a large part of these rocks as being Silurian or newer, 478; Kerr admits doubt in regard to the validity of his results, 478. No satisfactory reference of any of the rocks of this State older than the Trias, 479.

SOUTH CAROLINA.

Lieber's work gives no clue to the age or order of succession of the older crystalline rocks of this State, 479; Hunt, however, from Lieber's description, considers that he identifies the Green and White Mountain series, 479; Hunt's inferences, so far as can be made out, in contradiction with the statements of Lieber, 480.

GEORGIA.

Little says that there is no Azoic in this State, 480; Hunt, on lithological grounds, refers some of the rocks to the Montalban, and some to the Taconian, 480.

TEXAS.

Buckley's reports noticed and criticised, 480, 481; they are of no importance, 481.

TENNESSEE.

Safford on the older rocks of this State, which he sees no reason for referring to the Laurentian or Huronian, 481. Bradley holds that all the metamorphic rocks of Tennessee are of Silurian age, 481.

ARKANSAS.

Owen's views in regard to the crystalline rocks of this State; he holds that they are eruptive, 482.

MISSOURI.

Nothing definite known in regard to the crystalline rocks of this State, except that most, if not all, of them are eruptive, 482; they have been assigned to the Huronian and Laurentian on lithological grounds solely, 482.

MICHIGAN AND WISCONSIN.

Reference to work recently published by Wadsworth in regard to the geology of this region, 482. Age of the cupriferous rocks of Lake Superior discussed, 482–494; evidence obtained on branch of Torch River, 482–485; nature of these rocks indicated, 483; the facts discussed, 484; conclusions reached, 485. Irving, in 1873–74, on the relations of the Lake Superior rocks, 485, 486; he adopts a different theory, in part, in 1879, 486; Sweet states facts in opposition to the views of Irving, 486; our explanation of the phenomena, 487. Irving finds evidence in support of his views at the Dalles, 487; Chamberlin holds the same opinion of this locality, 488. Selwyn, in 1882, states his views as to the age and relations of the Lake Superior rocks, which he had previously called Huronian, 488; these views identical with those of Foster and Whitney, published in 1850, 488. Irving replies to Selwyn, 489; Wadsworth replies to Irving, 489. Hunt, in 1883, states that Logan, in 1863, put forth conclusive evidence that the cupriferous rocks of Lake Superior underlaid, unconformably, the Potsdam sandstone, 489; Wadsworth points out that Logan brought no such evidence, 489. N. H. Winchell agrees with Foster and Whitney, and with Selwyn, 480. Chamberlin sums up his reasons for supposing the Keweenaw rocks distinct from the adjacent sandstones, 489, 490; the errors in his reasoning pointed out, 490. *Résumé* of the facts at the Taylor's Falls locality, 490; assumptions of the Wisconsin geologists, 490; what Owen saw there in 1850, 490, 491. Observations of Kloos, in Report for 1881, 491. N. H. Winchell thinks the sandstone at this locality more recent than the Potsdam, 491. Errors fallen into by Irving and Chamberlin pointed out, 491. The so-called "Keweenawan Series" owes its origin to incorrect observations, and erroneous deductions, 491, 492; N. H. Winchell, in 1881, gives a summary of the opinions held regarding the copper-bearing rocks, made up from one previously published by Wadsworth, 492. Wadsworth points out the ignorance of the principles of geology and lithology displayed by Brooks and Pumpelly, 492; they borrow largely from Foster and Whitney's map without giving any credit, 492. Rominger on the Azoic rocks of Michigan, 492, 493; his views in regard to the eruptive character of the granites, 493; his peculiar theories of the eruptive rocks, 493, 494; his observations in the Menominee region, 494. Discussion of the origin of the iron ores in a previous publication, by Wadsworth, referred to, 494. The views maintained by Foster and Whitney, and by Wadsworth, sustained by Selwyn, 494; these views opposed by Dana, 494; his reasoning criticised, 494; Newberry also expresses his opinion on the subject, 495 ; Julien does the same, 495 ; both these writers show by their writings that they have made no investigation of the facts, 495. Sweet, in 1876, on a supposed unconformability of the Huronian and Laurentian at Penokee Gap, 495, 496 ; Irving on the same, 496 ; nature of such occurrences not understood by the Wisconsin geologists, 496. Irving on the Huronian in Wisconsin, 497 ; his ignorance of the necessary results of the intrusion of an eruptive into a sedimentary one, 497 ; Irving adopts some of Wadsworth's lithological views, but omits to state the source from which they were derived, 497, 498. Hall, in 1866, refers the gneiss and granite of Redwood River to the Laurentian, and some quartzites in Minnesota to the Huronian, 498 ; Hall's views opposed by Hayden and N. H. Winchell. The cupriferous rocks on Lake Superior, within the limits of Minnesota, referred to the Potsdam, in 1880, by N. H. Winchell, 498.

THE FORTIETH PARALLEL SURVEY.

What rocks are included in the "Archæan" by the Fortieth Parallel geologists, 499, 500. The Azoic or Archæan rocks of the Laramie Range, 500; Zirkel's distinctive characters of eruptive and sedimentary granites, 500, 501 ; defect of his methods, 501 ; King's and A. Hague's statements at variance with each other, 501. The Medicine Bow Range referred to the Huronian by A. Hague, 502 ; no proof given that it is older than Tertiary, 502; defects of observation, 502. The Uinta Range, 503. The Wahsatch Range, gradual change of views in regard to its age, as volume succeeded volume, 503–507. Conflicting statements of Zirkel and King, 507, 508. Criticism of King's statements, and of his manner of observing, 508 ; similar criticisms by Geikie, 509, 510. Summing up of the results of the Fortieth Parallel Survey, and indication of their value, 510, 511.

HAYDEN'S SURVEY.

The rocks of the Chugwater, in 1868, called Laurentian, but no reasons given for this, 511, 512 ; Hayden, in 1869, states his theoretic views in regard to igneous and metamorphic rocks, 512. Hayden calls the rocks on the north side of the Uinta Range Silurian and Huronian, 512 ; the Fortieth Parallel Survey calls them Carboniferous, Powell Devonian, Emmons Cambrian, and Marsh Silurian, 512, 513. Endlich, in 1874, calls all the crystalline rocks in the region studied by him, at the head of the Rio Grande and Rio Animas, Metamorphic Palæozoic, 513. Statement of Peale in regard to crystalline rocks, 513. Endlich divides the Azoic rocks into three systems, 513, 514 ; he admits the insufficiency of his observations, 514. Remarks by St. John and Peale, 514. Summing up of the condition of things in the Rocky Mountains, 514, 515.

WHEELER'S SURVEY.

No evidence offered in regard to the Azoic, 515. Stevenson in regard to age of rocks called Archæan, in parts of New Mexico and Colorado, 515.

JONES'S SURVEY.

Comstock on the Azoic rocks of Northwestern Wyoming, 515. No reasons other than lithological for calling these rocks Laurentian, 515, 516.

POWELL'S SURVEY.

Report by Newton and Jenney on the Black Hills, 516; the Azoic rocks divided into Laurentian and Huronian, but on very slight evidence, 516.

CALIFORNIA.

Results of the California Survey, 516, 517. Hunt's views in 1866, and in 1868, before visiting the region, 517. He spends several days there, and discovers that rocks of the Sierra Nevada which contain Jurassic fossils are of Huronian age, 517, 518. Hunt's views of Californian geology shown to be fundamentally wrong, 518.

PART II.

Résumé, and General Discussion.

Introductory remarks, 519. The geology of Canada and New England in an almost hopeless state of confusion, 519, 520. How this condition of things has been brought about, 520. The establishment of the Silurian System by Murchison, in 1845, opens the way to the discussion of the question whether the lowest limit of life had been reached, 520. First use of the term Azoic by Murchison, 520, 521; his definition of that term, 521; his hesitating and contradictory statements in regard to it, 521; his gradual withdrawal of it in the successive editions of Siluria, 521, 522. Barrande's grouping, in 1846, of the Protozoic and Azoic rocks, 522; confusion caused by the use of the term Cambrian already begun, 522. Foster and Whitney, in 1851, describe certain rocks on the south shore of Lake Superior, under the designation of the Azoic System, 522. Similar rocks, in Canada, called by Logan the Metamorphic Series, but without fully ascertaining their geological position, 523. Logan, in 1854, applies the name Laurentian to these rocks, 523; confusion introduced by his inability to distinguish between the Azoic and the Palæozoic, 523. The term Azoic for some time in current use in this country, 523, 524; Dana's use and definition of it in 1862 and 1871, 524; his views in regard to the existence of life during an "azoic" period, 524; the position assumed by him in 1874, and the introduction of the term Archæan, with a definition of it, 524. Confusion of views in regard to the older crystalline rocks, 525. Some general remarks introductory to the consideration of the subject, 525; great interest attaching to the question whether life exists in other worlds than our own, 525; importance of fixing the epoch when life began here,

525. What is meant by the term Azoic, and what rocks may be included under that designation, 526, 527. How Foster and Whitney used the term Azoic, 527. The condition of things in regard to the propriety of the use of that term, 527. Injustice done by Logan in his introduction of the name Laurentian, 527, 528. Discussion of the question whether the term Archæan ought to replace that of Azoic, 528. Examination of the Eozoön question, 528–538; first announcement of its existence by Logan, in 1858, 528; Dawson, in 1864, announces that it belongs to the Rhizopods, and that its discovery will be "one of the brightest gems in the scientific crown of the Geological Survey of Canada," 529; further investigation of the Eozoön by Carpenter, and its recognition by him as a *Foraminifer*, 529; his authority insures its general recognition as the earliest known representative of life, 529; opposition, however, begins to manifest itself, 529; gradual accumulation of an eozoönal literature, but general acceptance of the *Eozoön Canadense*, 530; difficulty in the way of proving that it was not organic, 530; how Möbius overcame this difficulty, 530, 531; his results, and the characterization of them by Zittel and F. Roemer, 531; Leidy's views, 531; our own investigations into the character of the "Eozoönal limestones" of Eastern Massachusetts, 532–534. Prevalent tendency among palæontologists, at the present time, to find traces of organic life in all kinds of rocks, such as granite, lava, and even in slag — this accounted for, 534. Some evidence in regard to the ability of Carpenter and Dawson to distinguish minerals from fossils, 534–537. Extraordinary discoveries of Otto Hahn, and their bearing on the Eozoön question, 537, 538. Question discussed whether the existence of limestone and graphite is a proof of the presence of life at the time of their formation, 538–544. Bischof's views in regard to the existence of carbon during the primeval epoch, 538; his evidence controverted, 538–543; graphite in cast-iron, 538; in the crystalline rocks, 539; not formed as coal has been, 540; plumbago not always graphite, 540; the artificial production of graphite, and of the diamond, 540; graphite formed in the Le Blanc process, 541; Bischof's ideas in regard to the mode of occurrence of the diamond shown to be incorrect, 541, 542; how it does occur, in connection with gold, 542; in South Africa, in volcanic rocks, 542, 543; some facts in regard to the peculiar circumstances under which the diamond must have been formed, 543. Examination of the current idea that the presence of carbonate of lime is proof of the existence of life at the time this was formed, 543, 544. Similar inquiry in regard to iron, 544; in regard to sulphur, 544, 545; phosphoric acid, 545. No encouragement given, by the investigations of the past half-century, to the idea that below the Primordial or Potsdam zone there is another series of fossiliferous rocks, 545. The wish father to the thought, 545, 546; Lyell "revels with delight" (*fide* Murchison) at the discovery of the Eozoön, 545. Difficulty in which evolutionists are placed by its adoption, 546; F. Roemer's statement of the case recommended for consideration, 546. Remarkable result of palæontological investigations — one and the same fauna over the whole globe during the Primordial epoch, 546. Inferences with regard to the azoic character of the Azoic series, 546. Inquiry into Dana's use of his term Archæan, 547–550; he includes under that designation rocks of different ages, both fossiliferous and non-fossiliferous, 547; the importance of recognizing in our nomenclature the epoch of the first introduction of life upon the globe, 547. Dana believes that a part

of the Archæan rocks are fossiliferous, and states what the life of that epoch must have probably been, 548; his "abundance of life," however, only a theoretical abundance, 548. All eruptive and crystalline rocks, except the metamorphic Palæozoic and post-Palæozoic, according to DANA, "Archæan," 548, 549; unphilosophical character of this idea, 549, 550.

Inquiry into the propriety of the division of the Azoic (Archæan) into two or more groups, 550–560; according to DANA'S views, this absolutely necessary, 550. The attempts of the Canada Survey to do this on the evidence of fossils, 551, 552; the *Aspidella* and *Arenicolites*, 551, 552. Geological time kept by the order of succession of life, and not by means of minerals, 552; the Canada Survey, and the results of its attempts to follow the latter method, 552.

How such methods came to be in vogue, 552. By what principles the Canadian Survey was governed, 553. LOGAN the author of them, 553; with what training he began it, 553, 554; his age at the time he published his first scientific paper, 554; the influences under which he worked, 554; he follows LYELL implicitly, 555; he begins the work with certain theoretical assumptions, the truth of which he never investigates, 555; how his erroneous interpretation of the geology of Lake Huron and Lake Superior led him to false conclusions, 556. The Report of 1863 assumed certain things as having been proved which had not been, 556. HUNT'S statements about his own or other people's work not to be accepted as authority until his quotations have been compared with the original authorities, 556. The question of the nonconformity of the Laurentian and Huronian looked into, 556; what *ought* to be seen if the two are unconformable, and what *is* seen, 556, 557; SELWYN'S statements on this point, 557. What takes place when eruptive rocks begin to be acted on by erosive agencies, 557. What basis of fact underlies the division of the Azoic rocks into two series, 558, 559. LOGAN takes the ground that lithological characters are sufficient for the arrangement of rocks in chronological order, 559; in accordance with this view, the rocks previously called Huronian still farther differentiated, 560; the gabbros thus separated, 560; the Hastings series, demonstrated by VENNOR to be continuous with the Laurentian, made into the Montalban and Taconian, 560; the Arvonian, 560. Tabular arrangement of the rocks as at present adopted by the Canada Survey, 561; some improvements, and a carrying farther forward of the same idea, suggested in another table, 562; comments on this mode of work, 562. Importance to American geologists of having the work of the Canada Survey done according to better methods, 562.

APPENDIX: Examination of some of IRVING'S statements, made in the Third Annual Report of the United States Geological Survey, 563–565.

PART I.

Synopsis of the Evidence on which the Rocks of the Azoic System have been variously grouped into Distinct Divisions by American Geologists.

In the following discussion the various regions where rocks of the Azoic System occur will be taken up and examined in a geographical order, beginning with that part of the North American continent where these rocks have their greatest development, and where, in course of a geological survey carried on continuously for more than forty years, a large portion of the material has been published which will here come under review. In order to prevent misunderstandings, and as an important assistance to those who may hereafter wish to make an independent examination of the questions here discussed, the exact language of the author quoted will be given in as much fulness as seems desirable, although this course must necessarily considerably increase the length of this paper.

CANADA.

Sir Wm. Logan, in the Report of Progress of the Canada Geological Survey for 1845–46 (pp. 40–51), described a series of rocks which he, following Lyell, called the "Metamorphic Series." This he divides into two divisions, one composed in general of "syenitic gneiss," the other of the same rock with intercalated bands of crystalline limestone. The relations of these to each other can be best expressed in Logan's own words: —

"To the south of the Mattawa and of the Ottawa in its continuation after the junction of the two streams, important beds of crystalline limestone become interstratified with the syenitic gneiss, and their presence constitutes so marked a character that it appears to me expedient to consider the mass to which they belong as a separate group of metamorphic strata, supposed from their geographical position and general attitude to overlie the previous rocks conformably. The limestone beds appear to be fewer at the bottom than at the top of the group, but whether few or many, they are always separated by beds of gneiss which in no way differs either in constituent quality or diversity of arrangement from the gneiss lower down, except in regard to the presence of accidental minerals, the most common of which are garnets." (*l. c.*, pp. 41, 42.)

It is thus seen that his divisions are arbitrary and theoretical, both being, according to his statement, conformable and interlaminated with one another. As regards the origin of the "syenitic gneiss," or lower formations, he writes that they possess "an aspect inducing a theoretical belief that they may be ancient sedimentary formations in an altered condition." (*l. c.*, p. 40.) The lamination planes of the gneiss (?) appear to be taken without hesitation as planes of sedimentation. As before, theoretic belief, and not evidence, was the basis on which all was decided, and Logan never went beyond this.

Without adopting any theory of the origin of the rocks in question, it is sufficient simply to point out that, accepting Logan's own statements as true, the rocks might, so far as the published evidence goes, have originated in any way not *a priori* impossible. His evidence is valueless excepting so far as credit may be given to the skill he may at that time have possessed in distinguishing metamorphic sedimentary from metamorphic eruptive rocks.

Later he stated : —

"The succession of rocks in ascending order, ... after crossing sixty-three miles, ... occupied by the unbroken uniformity of the lower metamorphic, or syenitic gneiss, formation, is as follows : —

"1. Chloritic slates and conglomerates.

"2. Greenish sandstones.

"3. Fossiliferous limestones." (*l. c.*, p. 67.)

The chloritic slates and conglomerates were said to hold pebbles and boulders of the subjacent gneiss. The limestones were regarded from their fossils as being of the age of the Niagara. Mr. Logan says : —

"The facts that have as yet come within my observation in respect to these formations have not been sufficient to enable me to determine to my own satisfaction what their relations are in respect to conformability. That the limestones are unconformable with the slates appears almost certain, but it is not in my power to state with which the intermediate sandstones are conformable, if they are so with either, or whether they are unconformable with both ; nor can I assert whether the slates are conformable with the gneiss." (*l. c.*, p. 69.)

We thus see that the chloritic slates and conglomerates, which later on lithological evidence were referred to the Huronian, were only shown to be older than the Niagara, their true age being unknown.

Logan in the Report of Progress for 1846–47 described the series on the north shore of Lake Superior in ascending order, as follows (*l. c.*, pp. 8–17) : —

> "1. Granite and syenite.
>
> "2. Gneiss.
>
> "3. Chloritic and partially talcose and conglomerate slates.
>
> "4. Bluish slates or shales, interstratified with trap.
>
> "5. Sandstones, limestones, indurated marls, and conglomerates, interstratified with trap.
>
> "The rock at the base of the series is a granite, frequently passing into a syenite by the addition of hornblende, but the hornblende does not appear to be often present wholly without the mica. . . . . The granite appears to pass gradually into a gneiss, which seems to participate as often of a syenitic as a granitic quality. . . . . The gneiss is succeeded by slates of a general exterior dark green colour, often dark-gray in fresh fractures, which at the base appear occasionally to be interstratified with beds of a feldspathic quality, of the reddish color belonging to the subjacent granite and gneiss. . . . . Some of the beds have the quality of a greenstone, others that of a mica slate, and a few present the character of quartz rock. Rising in the series, these become interstratified with beds of a slaty character, holding a sufficient number of pebbles of various kinds to constitute conglomerates. The pebbles seem to be of various qualities, but apparently all derived from hypogene rocks. . . . . The formations which succeed, rest unconformably upon those already mentioned. The base of the lower one [No. 4], where seen in Thunder Bay in contact with the subjacent green slates, presents conglomerate beds probably of no great thickness, composed of quartz pebbles chiefly, with a few of red jasper, and some of slate in a green arenaceous matrix, consisting of the same materials in a finer condition."

Reposing on the bluish slates (No. 4) are "sandstones, limestones, indurated marls and conglomerates interstratified with trap," and crowned by an enormous amount of volcanic overflow. No evidence is adduced to show that these two "volcanic formations" are unconformable with each other, but sufficient proof is cited to show that they are unconformable with the granite, gneiss, and chlorite slate. The volcanic formations are, however, regarded as being older than the Potsdam sandstone. (*l. c.*, p. 34.)

Logan further remarks : —

> "The chloritic slates at the summit of the older rocks on which the volcanic formations rest unconformably, bear a strong resemblance to those met with in the upper part of Lake Temiscamang on the Ottawa, and it appears probable they will be found identical." (*l. c.*, p. 34.)

Logan evidently held that the greenish slates (No. 3) were conformable to and continuous with the underlying gneiss, one rock passing into the other; while the conglomerates observed were not at the base of the slates, but quite high in the series. (Geol. of Canada, 1863, pp. 52–55, 64.) Dr. Hunt's language in his "Azoic Rocks" (p. 68) implies that Logan found a different relation between the gneiss and slate, — namely, unconformability with the conglomerate at the base.

Mr. Alexander Murray in the same report (1846–47) states that the rocks in the basin of the Kamanistiquia River are granite, syenite, gneiss, micaceous and chloritic schist, overlain by blackish argillaceous slates with associated trap.

Of the first series he says: —

> "Where they make their appearance at the lower end of the portage, the character of the rock is a red or in some instances a whitish massive syenite, which passes gradually into a gray gneissoid syenite, dipping at a high angle N. N. W. · Resting conformably on the gneiss, there occurs a series of dark greenish blue or greenish black altered slates, the one rock passing almost imperceptibly into the other. . . . . Towards the bottom near the junction with the syenitic portion, the slates are of a dark bluish and occasionally of a brownish color. They appear to be highly altered."

Of the black argillaceous slates Mr. Murray says: —

> "The base of this formation . . . . was observed on the Kamanitiquia near the Grand Falls. Its immediate junction with the rock on which it reposes was concealed from view, but appears to be indicated by the position of a small lake or pond, occurring just below the second portage, and the marshy ravines which run from it in the direction of the strike on each side. The slates visibly reach to within a short distance of the pond, probably brought into place against the syenite by a dislocation." (*l. c.*, pp. 51–53.)

The syenite and gneiss afterwards were assigned to the Laurentian, and the greenish blue or greenish black slates to the Huronian. Hence we see that at the only contact known for many years of the Laurentian and Huronian both series were conformable, *passing almost imperceptibly into one another.* Also, that near the junction the slates were highly altered. (Geol. of Canada, 1863, p. 64.) These facts are not mentioned by Dr. Hunt in his account of this report. (Azoic Rocks, pp. 68, 69.) It is, however, to be kept in mind, that at this time, as also when the Huronian was named and for some years later, Nos. 4 and 5, or the black slates, sandstones, traps, conglomerates, etc., constituting the copper-bearing series (Keweenawan, but really Potsdam) were held to be the exact equivalents of the schists and slates (Huronian) north of

Lake Superior, while the above greenish slates (No. 3) were not separated from the preceding rocks (Nos. 1 and 2) until many years later. (See Am. Jour. Sci., 1852, (2) XIV. 224–229; 1857, XXIII. 305–314; Azoic Rocks, pp. 71, 72, 80.)

In the Report of Progress for 1847–48, Mr. Murray gives some account of the sequence of the rocks on the islands and northern shore of Lake Huron.

> "The older groups observed consist, firstly, of a metamorphic series, composed of granitic and syenitic rocks, in the forms of gneiss, mica slate, and hornblende slate; and, secondly, of a stratified series composed of quartz rock or sandstones, conglomerates, shales and limestones, with interposed beds of greenstone;"

succeeded by fossiliferous formations, i. e. Potsdam sandstone, etc. Certain of the conglomerates of the second series are said to contain pebbles and boulders of syenite, but beyond this nothing is advanced to show the relations of this to the granitic and syenitic rocks, the two series not being seen in contact. The relation of the fossiliferous formations to the preceding series was shown clearly enough, the separation being a marked one. (*l. c.*, pp. 107–113.)

Mr. Murray further says:—

> "On a cluster of small islands . . . . Granite, [lithologically like the Laurentian,] was found breaking through the quartz-rock. . . . . The colour of the rock was red. On one of the islands, quartz-rock beds on opposite sides of the granite were observed to dip in opposite directions, north on the north side and south on the south side, at an angle of 70° or 80°; and in another of the islands the quartz-rock and granite were seen in juxtaposition, the former reclining on the latter. In this case the quartz rock was traversed by several trap dykes running slightly oblique to the strike, while granitic veins ran transversely through the whole, and were continued through a main body or nucleus of granite, the one granite being distinguishable from the other, notwithstanding the red color of both, by the finer texture of the veins." (*l. c.*, pp. 112, 113.)

In a "Report on the North Shore of Lake Huron," under date of December 29, 1848, Mr. Logan gives some account of the second series described by Mr. Murray, and states:—

> "The series of rocks occupying this country from the connecting link between Lakes Huron and Superior to the vicinity of Shebawenahning, a distance of 120 miles, with a breadth in some places of ten, and in others exceeding twenty miles, it appears to me, must be taken as belonging to one forma-

tion; on the west it seems to repose on the granite, which was represented in my report on Lake Superior as running to the east of Gros Cap, north of Sault Ste. Marie; on the east the same supporting granite was observed by Mr. Murray north of La Cloche, between three and four miles in a straight line up the Rivière au Sable, ... and again, about an equal distance up another and parallel tributary, ... in both cases about ten miles from the coast. . . . . In respect to the geological age of the formation, the evidence afforded by the facts collected last year by Mr. Murray . . . . is clear, satisfactory, and indisputably conclusive, ... successive formations of the lowest fossiliferous group of North America, were each in one place or the other found, in exposures divested of all vegetation, resting in unconformable repose, in a nearly horizontal position, upon the tilted beds, and undulating surface of the quartz rock, and its accompanying strata, filling up valleys, overtopping mountains, and concealing every vestige of dykes and copper veins. . . . . The chief difference in the copper-bearing rocks of Lakes Huron and Superior, seem to lie in the great amount of amygdaloidal trap present among the latter, and of white quartz rock or sandstone among the former. But on the Canadian side of Lake Superior there are some considerable areas, in which important masses of interstratified greenstone exist without amygdaloid, while white sandstones are present in others, as on the south side of Thunder Bay, though not in the same state of vitrification as those of Huron. But notwithstanding these differences, there are such strong points of resemblance in the interstratification of igneous rocks, and the general mineralized condition of the whole, as to render their positive or proximate equivalence highly probable, if not almost certain; and the conclusive evidence given of the age of the Huron, would thus appear to settle that of the Lake Superior rocks, in the position given to them by Dr. Houghton, the late State Geologist of Michigan, as beneath the lowest known fossiliferous deposits, a position which, as will be seen by a reference to the Report of Progress I had the honor to submit to your Excellency in 1846, appeared to me to derive some support from evidences on the Canadian side of Lake Superior itself." (*l. c.*, pp. 8, 9, 19, 20.)

In this is to be seen one of the attempts to decide geological age by lithological evidence, applied to rocks at great distances from one another, — a failure, in this case at least, as will be seen farther on. One of the writers has pointed out elsewhere that the statements in this report and in that for 1846–47 (p. 34) regarding Dr. Houghton's views are erroneous. (Bull. Mus. Comp. Zöol. 1880, VII. (Geol. Series I.) 83.) The views which Logan held regarding the age of the copper-bearing rocks of Lake Superior at the time of the publication of the report from which quotations have just been made, were published later in several papers. (Bull. Soc. Geol. France, 1849–50, (2) VII. 207–209. Report Brit. Assoc. Adv. Sci., 1851, Trans. Sec., pp. 59–62. Am. Jour. Sci., 1852, (2) XIV. 224–229.) In these publications the copper-bearing rocks of Lake Huron, and therefore those of Lake Superior, were regarded as being of Cambrian age.

In the Report of Progress for 1848–49, Mr. Murray again reported on the region north of Lake Huron. He arranges the rocks along the Spanish River into two series: the *granitic or metamorphic group*, and the *quartz rock group*. The first group "appeared to rise from beneath the rocks of the second group in two different localities," but no evidence seems to have been found to show the relations of the two supposed formations except the finding of pebbles of granite or syenite in some of the conglomerates of the second group. The rocks of the first group were said to be granite or syenite, except the following: —

> "A gneissoid structure was observed on one or two occasions, but it was for the most part obscure and ill-defined, being perceptible rather in a longitudinal arrangement of the constituent minerals, than in conspicuous beds of different quality." (*l. c.*, pp. 36–42.)

In the Report of Progress for 1849–50, a tract of country on the St. Lawrence River, between Bay St. Paul and Murray Bay, was described. Here the metamorphic group, consisting of gneiss, was overlain by white quartz rock (Potsdam sandstone). (*l. c.*, pp. 8–10.) In the Report for 1851–52, the *metamorphic or gneissoid group* is likewise said to be overlain by Potsdam sandstone in the country between Beauharnois and the Rivière du Nord. (*l. c.*, p. 6.)

In the Quarterly Journal of the Geological Society (Vol. VIII., 1852, p. 210), Mr. Logan states regarding the rocks north of Lake Huron: —

> "On Lake Huron the Lower Silurian group rests unconformably upon a siliceous series with only one known band of limestone, of about 150 feet thick, with leaves of chert in abundance, but as yet without discovered fossils. This series is supposed to be of the Cambrian epoch. It comprehends the copper-bearing rocks of that district, and with its igneous interstratified masses has a thickness of at least 10,000 feet. The gneissoid group, of which mention is made, is probably still older than this. Its conditions appear to me to make it reasonable to suppose that it consists of aqueous deposits in an altered state."

In the Report for 1852–53, but published in 1854, Mr. Logan writes: —

> "The name which has been given in previous Reports to the rocks underlying the fossiliferous formations in this part of Canada is the Metamorphic series, but inasmuch as this is applicable to any series of rocks in an altered condition, and might occasion confusion, it has been considered expedient to apply to them for the future, the more distinctive appellation of the Laurentian

series, a name founded on that given by Mr. Garneau to the chain of hills which they compose. The geological formations which underlie the district in ascending order would thus be as follows: —

"1. Laurentian series.

"2. Potsdam sandstone," etc. (*l. c.*, p. 8.)

It will thus be seen that when the name Laurentian was thus proposed, it was the exact equivalent of the Azoic of Foster and Whitney proposed four years before.

In "A Sketch of the Geology of Canada," by Dr. Hunt, occurs the first mention of the Huronian system as such.

"The shores of Lakes Huron and Superior offer a series of schists, sandstones, limestones and conglomerates interstratified with heavy beds of greenstone, and resting unconformably upon the Laurentian formation. As these rocks underlie those of the silurian system, and have not as yet afforded any fossils, they may probably be referred to the Cambrian system (lower Cambrian of Sedgwick.). . . . . This Huronian formation is known for a distance of about 150 leagues upon Lakes Huron and Superior, and everywhere offers metalliferous veins, which have as yet been very little explored." (Canada at the Universal Exhibition of 1855, pp. 427, 428.)

In the same paper Dr. Hunt says of the Laurentian system: —

"The rocks of this system are, almost without exception, ancient sedimentary strata, which have become highly crystalline." (p. 421.)

So far as we are able to find in the Reports of the Canada Geological Survey no evidence was advanced to prove this position; it was a purely theoretic assumption, as Logan states (*ante*, pp. 331, 332). Dr. Hunt also declares that the Huronian on the shores of Lakes Huron and Superior rests unconformably upon the Laurentian formation. This too was a theoretical belief instead of an observed fact, so far as the Reports bore evidence (p. 427), except in the case of the Lake Superior copper-bearing rocks (Keweenawan, Potsdam), at that time regarded as being the equivalent of the schists (Huronian) north of Lake Huron. (See Azoic Rocks, pp. 71, 72; also *ante*, pp. 334, 335.)

Of the chlorite schists in the valley of Lake Temiscaming it is written: —

"The chloritic schists probably correspond to the Huronian rocks, but it is difficult to fix the age of the sandstones which are destitute of fossils." (*l. c.*, p. 447.)

The first mention of the Huronian formation by name, found in the Reports of Progress of the Canada Geological Survey, is in Mr. Murray's Report for 1854, under date of June 11, 1855, (p. 125,) as follows: —

"Among the boulders on Lake Nipissing, many were observed to be of a slate conglomerate, and they were frequently of very great size; in their aspect and general character these have a very strong resemblance to the slate conglomerate of the Huronian series, from which in all probability, they are derived."

The next mention is in the Report for 1855, dated March 1, 1856, p. 134: —

"The pebbles and boulders of metamorphic rocks which abound in the gravel and clay deposits, and are numerously scattered over the surface, are clearly derived from the Laurentian and Huronian formations on the north shore of Lake Huron."

In the Report for 1856 (March 1, 1857, pp. 168, 172) it is stated: —

"The rocks of the region explored during the season, embrace two of the oldest recognized geological formatios, the Laurentian and Huronian. . . . . The difference in lithological character between the two formations was always sufficiently apparent, but though both were frequently found at short distances apart, the immediate point of contact was always obscure; and a mass of greenstone of rather coarse grain was usually the first intimation of the proximity of the higher rocks. . . . . Whether this greenstone is the result of an overflow contemporaneous with the upper formation, or an eruptive mass intruded at a later period, has not yet been ascertained."

Regarding the *hypersthene rock* which has since been set apart as the Upper Laurentian or Norian Series, Dr. Hunt in his Report for 1854 (April 1, 1855, p. 374) states: —

"The rocks about to be described belong to the crystalline strata of the Laurentide mountains, and occur, as far as yet observed, in close association with the crystalline limestones, which alternate with the gneissoid and quartzose rocks of the formation."

In Dr. Hunt's Report for 1856 (April 1, 1857, p. 451, see also Philosophical Magazine, 1855, (4) IX. 354, 355), it is written concerning the same rocks: —

"In the Report for 1854 I have described at some length a class of stratified felspathic rocks, which form an important part of the Laurentian series, and are associated with the calcareous and magnesian deposits of that ancient formation."

The Reports here referred to from 1853 to 1856 were not published until 1857.

The division of the Azoic rocks into Laurentian and Huronian, and Logan's view that the copper-bearing rocks of Lake Superior were of the same age as the Huronian rocks of Lake Huron, were opposed the same year by one of the present writers in the May number of the American Journal of Science (1857, (2) XXIII. 305–314). He also pointed out Logan's violation of the law of priority in appropriating the term Laurentian from Desor.* It was there shown that the reason Logan had for separating the Huronian from the other Azoic rocks was his (Logan's) belief that the copper-bearing rocks (Potsdam) of Lake Superior were the same as the Azoic schists north of Lake Huron : hence, as the copper-bearing rocks of Lake Superior rested unconformably on Azoic granites, etc., therefore the Lake Huron rocks must. Later, Logan abandoned his premises, but did not, however, give up his conclusion. (See Hunt, Azoic Rocks, p. 80.)

In the Proceedings of the American Association for the Advancement of Science (August, 1857, pp. 44–47), Mr. Logan made some statements regarding "the division of the Azoic Rocks of Canada into Huronian and Laurentian," the chief of which we reproduce here :—

> "The sub-Silurian Azoic rocks of Canada occupy an area of nearly a quarter of a million of square miles. Independent of their stratification, the parallelism that can be shown to exist, between their lithological character and that of metamorphic rocks of a later age, leaves no doubt on my mind that they are a series of ancient sedimentary deposits, in an altered condition. . . . So early as the year 1845, as will be found by reference to my report on the Ottawa district (presented to the Canadian government the subsequent year), a division was drawn between that portion which consists of gneiss and its subordinate masses, and that portion consisting of gneiss interstratified with important bands of crystalline limestone. I was then disposed to place the lime-bearing series above the uncalcareous, and although no reason has since been found to contradict this arrangement, nothing has been discovered especially to confirm it. . . . In the same report is mentioned, among the Azoic rocks, a formation occurring on Lake Temiscaming, and consisting of silicious slates and slate conglomerates, overlaid by pale sea-green or slightly greenish-white sandstone, with quartzose conglomerates. The slate conglomerates are described as holding pebbles and boulders (sometimes a foot in diameter) derived from the subjacent gneiss, the boulders displaying red feldspar, translucent quartz, green hornblende, and black mica, arranged in parallel layers, which present directions according with the attitude in which the boulders were accidentally inclosed. From this it is evident that the slate conglomerate was not deposited until the subjacent formation had been converted into

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* This paper of Prof. Whitney's, in common with some others, was accidentally omitted in Mr. Wadsworth's "List of Papers" appended to the "Notes on the Geology of the Iron and Copper Districts of Lake Superior," although reference was made to it in the text. (See also Canadian Journal, 1857, (2) II. 302.)

> gneiss, and very probably greatly disturbed; for while the dip of the gneiss, up to the immediate vicinity of the slate conglomerate, was usually at high angles, that of the latter did not exceed nine degrees, and the sandstone above it was nearly horizontal. In the Report transmitted to the Canadian government in 1848, on the north shore of Lake Huron, similar rocks are described as constituting the group which is rendered of such economic importance, from its association with copper lodes. This group consists of the same silicious slates and slate conglomerates, holding pebbles of syenite instead of gneiss, similar sandstones, sometimes showing ripple marks, some of the sandstones pale-red green, and similar quartzose conglomerates, in which blood-red jasper pebbles become largely mingled with those of white quartz, and in great mountain masses predominate over them. But the series is here much intersected and interstratified with greenstone trap, which was not observed on Lake Temiscaming. . . . . The group on Lake Huron we have computed to be about 10,000 feet thick, and from its volume, its distinct lithological character, its clearly marked date posterior to the gneiss, and its economic importance as a copper-bearing formation, it appears to me to require a distinct appellation, and a separate color on the map. Indeed, the investigation of Canadian geology could not be conveniently carried on without it. We have, in consequence, given to the series the title of Huronian. A distinctive name being given to this portion of the Azoic rock, renders it necessary to apply one to the remaining portion. The only local one that would be appropriate in Canada is that derived from the Laurentide range of mountains, which are composed of it from Lake Huron to Labrador. We have, therefore, designated it as the Laurentian series." (See also Canadian Journal, 1857, (2) II. 439–442; Canadian Nat. and Geol., 1857, II. 255–258.)

The logic of the last few sentences will appear to be of a somewhat peculiar character, when it is remembered that the name "Laurentian" had been adopted some two years before the name "Huronian" was used, and some four years before Mr. Logan's paper was read.

As we have pointed out before, the age of the Lake Temiscaming slates was unknown.

In the same Proceedings Mr. Logan published a paper "On the Probable Subdivision of the Laurentian Series of Rocks of Canada." Some limestone and associated labradorite rocks he would set apart, but does not propose any name for them. This division seems to be a local one based on lithological characters, as no evidence was advanced to show that this formation was not conformable with the remainder of the Laurentian, as it had been stated to be before. (Proc. Am. Assoc. Adv. Sci., 1857, XI. 47–51; Canadian Journal, 1858, (2) III. 1–5; Canadian Nat., 1857, II. 270–274.)

Dr. J. J. Bigsby, in 1862, regarded the Huronian as distinct from the

Cambrian, and intimately related to the Laurentian, giving among his reasons its marked similarity, lithologically, to the Laurentian, and the conformity of the Laurentian and Huronian; and stating that in the only place north of Lake Superior where the two systems have been seen in contact, they were found conformable. (Quart. Jour. Geol. Soc., 1863, XIX. 36–52.)

Two other localities spoken of by Dr. Bigsby were hypothetical, not actual observed contacts, as he supposed. (See Report on the North Shore of Lake Huron, 1849, pp. 8, 9; Report of Progress, 1848–49, p. 36.)

In the Report on the Geology of Canada, 1863, the so-called gneisses of the Laurentian series are assumed to be stratified, and although the acknowledgment is made that the supposed beds "when thick, which they usually are, might on first inspection be mistaken for intrusive igneous instead of altered sedimentary masses." That they are really sedimentary is supposed to be shown by the minerals being obscurely arranged in parallel lines "conformable with the more distinctly banded portion of the strata." (*l. c.*, p. 23. See also p. 587.)

In fact Mr. Logan states. "The rocks which compose the Laurentian mountains were shown by the Geological Survey, in 1846, to consist of a series of metamorphic sedimentary strata, underlying the fossiliferous rocks of the Province." We have pointed out that nothing of the kind was shown by the Survey; but that there was only an announcement of "a theoretic belief that they may be ancient sedimentary formations in an altered condition." (Geol. Survey of Canada, 1845–46, p. 40, 1863, p. 22; Azoic Rocks, p. 66; *ante*, p. 332.)

Mr. Logan further states, that it is difficult north of Lake Huron to distinguish the Laurentian gneiss from an intrusive granite. (Geol. of Canada, 1863, p. 61.)

Regarding the relation of the Huronian to the Laurentian nothing that can be called evidence is advanced, except in one place; but, as usual, some general assertions are made. The following extract will give an idea of what was actually known of the relations of the two formations, with the exception to be mentioned later.

> "In that part of the country on the north shore of Lake Huron which lies between Mississagui and St. Mary Rivers, where the Huronian series has been more completely examined than elsewhere, the immediate contact of the gneiss with the overlying rocks has not been observed. On the coast line between the Mississagui and Thessalon Rivers, a distance of about twenty-five miles, the gneiss extends from within about four miles of the former to within about

the same distance from the latter ; but it is very much disturbed by intrusive granite and greenstone, and, although there are great exposures of rock, it is very difficult to make out how the stratified portions are related to one another. The gneiss extends to the vicinity of a small stream about a mile and a half above Les Grandes Sables, and what is supposed to be the lowest Huronian mass of that part occurs about half a mile above the stream. It consists of a grey quartzite which abuts against one mass of gneiss and runs under another, and appears to be much broken by and entangled among the intrusive rock ; but judging from a transverse measure in one part, its thickness would not be far from 500 feet." (*l. c.*, p. 55.)

It would seem that here the Huronian was found abutting against and underlying the Laurentian gneiss (granite). In none of the sections given do the conglomerates in the Huronian appear to lie at the base of the formation, but at varying heights in the series.

The exception referred to above is this : under the head of "Contact of Laurentian and Huronian Rocks," it is stated that in the upward navigation of the Kaministiquia River

"the first development of the Laurentian series occurs at the second portage, about half a mile above the Grand Falls. At the lower end of the portage, where the series makes its appearance, the rock resembles a massive syenite, in some parts red and in others whitish, but is probably a hornblendic gneiss in which the lamellar arrangement of the constituent minerals is obscure, as the rock gradually passes into such a gneiss. Resting on it conformably there occurs a series of dark greenish-blue or greenish-black slates, the one rock passing almost imperceptibly into the other. The section occupies upwards of a quarter of a mile on the river bank, and at the upper end of it, as well as at the head of the portage, the dip is N. 54° E. . . . . At each rapid part of the river above the Grand Falls there is a greater or less development of these rocks, most frequently presenting the more distinctly stratified part of the gneiss. The best exposure of the slates is at the Three Discharges, about four miles above the Grand Falls, where the rocks are observed to pass from the gneiss to the slate. . . . . Towards the bottom, near the junction with gneiss, the slates are of a bluish and occasionally of a brownish color." (*l. c.*, pp. 64, 65.)

It would then appear that Huronian in the only localities, except one problematical one (*l. c.*, pp. 52–54, 703), in which it had been seen in contact with the Laurentian, was conformable with and passed almost imperceptibly into, or else underlaid, the Laurentian.

An intrusive granite is said to occupy

"a considerable area on the coast of Lake Huron, south of Lake Pakowagaming. It there breaks through and disturbs the gneiss of the Laurentian series, and forms a nucleus from which emanates a complexity of dykes, proceeding to considerable distances. As dykes of a similar character are met with intersecting the rocks of the Huronian series, the nucleus in question is supposed to be of the Huronian age, as well as the greenstone dykes which are intersected by it." (*l. c.*, p. 58.)

Mr. Logan seems in this report to have abandoned the idea that the copper-bearing rocks of Lake Superior were of the same age as those north of Lake Huron, except in some minor districts classed as Huronian; for he calls the Huronian formation the Lower Copper-bearing rocks, and places the others as the Upper Copper-bearing rocks. These latter rocks he divides into two groups, and writes of their age as follows: —

> "The precise age of the upper copper-bearing rocks of Lake Superior is a question attended with some difficulty. Mr. Whitney appears disposed to regard the whole series from the summit of the sandstones of Sault Ste. Marie to the base of the Kaministiquia slates as one group equivalent to the Potsdam formation; but the suspicion of a want of conformity between the Sault Ste. Marie sandstones and the trappean rocks beneath, would induce us to separate the two. . . . . The affinities of the red sandstone of Sault Ste. Marie would thus appear to bring it into the position of the Chazy rather than the Potsdam formation; and if this were established, the copper-bearing portion of the Lake Superior rocks might reasonably be considered to belong to the Calciferous and the Potsdam formations." (*l. c.*, pp. 84–86.)

This is an abandonment of the attempt to determine the age of the Lake Superior copper-bearing rocks by lithological characters only, and, so far as Mr. Logan is concerned, a removal of those rocks from the Azoic series.

In the supplement to this report the labradorite rocks occurring in the Laurentian series are thought to unconformably overlie the lower portion of the Laurentian formation, cutting out some limestone bands. The contacts were not seen; but, as the labradorite rocks were assumed to be sedimentary, this replacement of the limestone was held to prove their unconformability with the Laurentian. (*l. c.*, pp. 837–839.)

The same year Dr. Hunt remarked: —

> "The so-called granites of the Laurentian and Lower Silurian appear to be in every case indigenous rocks; that is to say, strata altered *in situ*, and still retaining evidences of stratification. The same thing is true with regard to the ophiolites and the anorthosites of both series; in all of which the general absence of great masses of unstratified rock is especially noticeable." (Am. Jour. Sci., 1863, (2) XXXVI. 226.)

In the Report of Progress from 1863 to 1866 (pp. 127–129), Mr. Thomas Macfarlane describes the contact of some supposed Huronian with Laurentian rocks as follows : —

" The manner in which these Huronian rocks adjoin those of the Laurentian series may be observed on the north shore between Michipicoten Harbour and Island. I paid some attention to that point of junction which lies to the west of Eagle River, the precipitous cliffs to the east of which, consist principally of diabase schist and greenstone slate. A few miles to the west of these cliffs, and at a point bearing N. 29° 5° E., from the east end of Michipicoten Island, the Laurentian granite is penetrated by enormous dykes of dense basaltic greenstone (having the peculiar doleritic glitter when fractured) which contain fragments of granite. This greenstone is also seen in large masses, which can scarcely be called dykes, overlying the granite, and enclosing huge masses of that rock, one of which I observed to be cut by a small vein of the greenstone. From this point to Eagle River, those two rocks alternately occupy the space along the shore, seldom in such a manner as to shew any regular superposition of the greenstone on the granite, but almost always more or less in contact with each other. The greenstone, however, becomes more frequent towards the east, and at Eagle River it has almost replaced the granite, and assumed a lighter colour, and an irregular schistose structure. The strike of these schists is at places quite inconstant ; they wind in all directions, and what appear at first sight to be quartz veins, accompany their contortions. On closer inspection, however, of the largest of these, they are seen to be of granite, but whether twisted fragments of that rock, or really veins of it, is at first glance very uncertain. Observed superficially they have the appearance of veins, but they do not preserve a straight course, and bend with the windings of the enclosing schist. They often thin out to a small point and disappear, and, a few feet or inches further on in the direction of the strike, reappear and continue for a short distance. Sometimes a vein thins out at both ends, and forms a piece of granitic material of a lenticular shape, always lying parallel with the stratification. Although they are seldom or never angular, they can scarcely be regarded otherwise than as fragments whose shape has been modified by contact with the greenstone. . . . . There would seem to be only two ways of explaining the phenomena above described. Either the granite forms veins, penetrating the schistose greenstones, in which case the latter are the older rocks ; or it is in the form of contorted fragments, in which case the inclosing rocks may be of eruptive origin. The latter supposition seems to be most in harmony with the facts stated, and with what is known as to the relative ages of the Laurentian and Huronian rocks. I may here remark that in Foster and Whitney's Lake Superior Report (Part II., pp. 44 and 45) analogous phenomena are described, but the exactly opposite conclusion is arrived at, viz.: that the granite is in veins, and forms the newer rock. Similar relations are observed at other points of junction on the north shore, and the peculiar breccia, described among the greenstones above mentioned, occurs at no great distance from one of these. It is remarkable that the greenstone found associated with it is also basaltic, and this is also the case with the trap occurring at the junction of the two formations in the northeast corner of Bachewahnung Bay. Here it is finer grained, but still possesses the glittering fracture of basaltic greenstone. The Laurentian rock is a highly granitic gneiss, and pieces of it are enclosed in the black greenstone, which at one place seems to underlie the granite. A reddish-grey felsitic rock, with conchoidal fracture, is observed at the point of junction. Eastward from it banded traps occur, striking N. 55° W., together with greenstone breccia and conglomerate of the characters already described. On ascending the hills behind this point a breccia is observed, of which the matrix is greenstone, and the fragments granite. The lines of junction between the Laurentian and Huronian series, and between these and the Upper Copper-bearing rocks, so far as observed during the exploration, are given on the accompanying map. With regard to the succession of the strata, I found myself as much at a loss among the irregularly schistose Huronian greenstones, as among the gneissoid granites of the Laurentian."

It seems almost incredible that a geologist, who professed to be a lithologist, should have been unable to ascertain the relations and relative age of these rocks, when so many excellent exposures were observed as he states. His observations show clearly that both formations here are eruptive, and of the same geological age.

In the *Esquisse Géologique du Canada* (Paris Exhibition of 1867, p. 10) the Huronian is said by Dr. Hunt to repose unconformably on the Lower Laurentian formation, and probably also on the Upper Laurentian. It is to be remembered, however, that at the locality on the Kaministiquia River, in which the Huronian had been seen in contact with the Laurentian, the two were found to be conformable. (Geology of Canada, 1863, pp. 64, 65.)

In the same paper (p. 5) Dr. Hunt claimed that the Laurentian comprised two distinct series of rocks, of which one reposed with discordant stratification on the other: these he calls the Lower Laurentian and Upper Laurentian, or Labradorian.

In the Report of Progress for 1866–69, Mr. James Richardson reports, that in the region north of the lower St. Lawrence River

"the Laurentian gneiss sometimes has little appearance of stratification; the strike is generally north and south, with dips often approaching vertical. The strata are all more or less broken, contorted and faulted. The labradorite rocks rest unconformably on the Laurentian; they generally strike nearly east and west, and dip at comparatively moderate angles, with little or no appearance of contortion or disturbance. . . . . The reddish quartzose granitoid rock of the Laurentian is again met with, offering no evidence of stratification; and in one place is seen to be distinctly overlaid by a patch, only a few yards square, of labradorite-rock, shewing considerable varieties in character, and clearly stratified." (*l. c.*, pp. 305–307.)

Mr. Richardson's work failed to prove his conclusions, as the rocks were not shown to be sedimentary.

In 1868 Mr. J. Marcou wrote regarding the Laurentian and Huronian formations: —

"The Laurentian system is composed of the Lower Taconic, to which are added all the unstratified crystalline rocks forming the centre of the Laurentine Mountains, such as granite, syenite, diorite and porphyry, mixing together strata and eruptive rocks, an attempt which was unexpected from a stratigraphical geologist. His Huronian system is formed of a mixture of the St. Albans group of the Upper Taconic, with the Triassic rocks of Lake Superior, the trap native-copper bearing rocks of Point Keeweenaw, and the dioritic dyke containing the copper pyrites of Bruce mine on Lake Huron." (Proc. Bost. Soc. Nat. Hist., 1861, VIII. 246, 247.)

In the Report of Progress for 1870–71, Mr. Robert Bell points out a case of an apparently conformable junction of the Huronian and Laurentian rocks. He remarks: —

"From the mouth to the sixteenth portage . . . . the river [White River] runs entirely upon greyish and reddish gneiss, mostly of a massive granitic character [Laurentian], striking W. S. W., and dipping northward at angles varying from 30° to 80°. It is occasionally interstratified with bands of dark hornblendic schist and very light grey gneiss. Fine dark green hornblendic schists [Huronian], having the same strike, occur between the sixteenth portage and the outlet. . . . . Similar schists [Huronian], with bands of gneiss, appear to rest conformably upon the massive gneisses at a short distance north of the river, all the way from Natamasagami Lake to the mouth (28 miles)." (*l. c.*, p. 345.)

Of another locality Mr. Bell, in the Report for 1871–72, states: —

"Towards the end of the above twenty miles, bands of gneiss become interstratified with the schists, and just at Martin's Falls the latter have become entirely replaced by red and grey gneiss, apparently shewing a conformable passage from the Huronian into the Laurentian rocks. What appeared to be a similar blending of these formations was noticed last year in the neighborhood of White Lake." (*l. c.*, p. 110.)

In the Report of Progress for 1872–73, Mr. Bell again states, regarding the rocks northwest of Lake Superior: —

"As mentioned in the present and in my previous reports on this region, the Huronian rocks appear to succeed the Laurentian conformably, the distinction between the two being chiefly of a lithological character. As nearly as the distribution of the two series can be mapped by means of our present data, it would appear that the various bands of each set of rocks in contact with each other, correspond in their general run, and partake of the same curves and flexures." (*l. c.*, p. 106.)

Regarding Mr. Bell's observations Mr. Selwyn states: —

"It may, however, be remarked that though the facts observed undoubtedly lead to the conclusion, as stated by Mr. Bell, that the two series are in conformable sequence, yet it is far from improbable that this apparent conformity is only local, and that the result of a more extended and detailed investigation of the structure would serve to shew that there is in reality a very considerable break and much unconformity between the Laurentian gneiss and the overlying schistose and slaty strata. As regards the age of these so-called Huronian rocks, the evidence is not of the most satisfactory kind. While stratigraphically they rest directly upon highly crystalline and typical Laurentian gneisses, mineralogically they resemble as closely the chloritic, epidotic and dioritic strata of the altered Quebec group as they do those which on the shores of Lakes Huron and Superior are referred to the Huronian series." (*l. c.*, pp. 13, 14.)

In this connection it is well to remember that these rocks were referred to the Laurentian and Huronian on the same evidence that four fifths of the rocks so called are, — lithological, namely, — and that the evidence of conformability given by Mr. Bell is just as strong as any of the evidence of unconformability; also, that Logan had shown that the two formations were conformable. Moreover, it had been shown that the Huronian lay beneath the Laurentian. We do not see that Mr. Selwyn's statement has any basis of fact, it being decidedly opposed to all the evidence collected by the Canada Survey.

In the Report for 1872–73 (p. 104), Mr. Bell states: —

"The junction of the Laurentian rocks on the north with the Huronian schists of the Lake of the Woods on the south takes place on Rat Portage. The two rocks are seen almost in contact with each other, and have the same strike and dip."

Mr. George M. Dawson says of the same locality: —

"The southern end of the path passes over Huronian rocks. . . . . At the water's edge . . . . they were found to be vertical, with a strike of N. 75° E. About half-way across the Portage, and at its highest part, the rocks dip N. 17° W. < 48°, and are then immediately succeeded by Laurentian gneiss, which is granitoid, and of a light pinkish-grey colour; dip N. 30° W. < 89°. The junction is so close that one may actually lay the hand upon it, and the separating line is remarkably straight and even. Followed about one hundred yards westward, it was found to preserve the course of S. 67° W., or nearly that of the strike of both series of rocks. The gneiss at this distance has a strike of N. 72° E., and the green slate, just across the line of junction, and only a few yards removed, N. 73° E." (Report on the Geology and Resources of the Region in the Vicinity of the Forty-ninth Parallel, 1875, p. 45.)

Mr. Dawson continues :—

"A mile still further eastward . . . . the Winnipeg River . . . . falls northward, across the junction of the Laurentian and Huronian series, through a narrow passage between rocky cliffs. At the fall, the rock is . . . . much hardened and of greenish colour ; dip N. 10° W. < 45°. Just below the fall, the red gneiss again suddenly appears with a dip N. 18° E. 78°. . . . . Notwithstanding the close accordance of the strike of both series of rocks, and the direction of the line of junction, the evidence appears to be nearly conclusive, that the two formations are here brought together by a fault, with an extensive downthrow southward. If they are thus in contact merely by sharp folding, the relative position must be reversed, as the dips would carry the slate series below the gneiss." (*l. c.*, p. 46.)

Mr. Dawson in explaining this line of contact proceeds on the supposition that both formations are sedimentary, and hence offers the only explanation he can and preserve the Laurentian in its supposed position. Yet, so far as his descriptions go, one or both may be eruptive, which would explain the observed facts just as well. It is a pity that, with so much contact observed, he did not ascertain whether the contact was the rubbing, grinding division-plane contact of a fault; or the contact produced by one rock laid conformably, or unconformably, upon another, and both folded ; or the close-welded, altering contact of an eruptive rock. Had he carefully observed the phenomena of the contact, he might have built on facts, and thus have been saved much useless speculation.

Of another locality Mr. Dawson remarks :—

"The rocks . . . . belong, as I believe, to an area of much-altered Huronian. . . . . The actual junction between the two formations at this point is concealed by water, but they show a remarkable appearance of conformity, the next rock seen, being a soft greenish slate, with a dip of S. 60° W. < 45°. [The previously given dips of the Laurentian were S. 60° W. < 50°, and S. 45° W. < 60°.] It is worthy of notice that similar apparently conformable junctions of Laurentian and so-called Huronian rocks have been noticed by Prof. Bell, as occurring on the Albany River at Martin's Falls, and also in the neighbourhood of White River." (*l. c.*, p. 29.)

Mr. Bell in the Report of Progress for 1877–78, speaking of the junction of the Laurentian and Huronian in the Hudson's Bay district, says: —

> "The junction of the two formations, which appear as usual to be conformable with each other, occurs just where the southwest area opens into the main body of the lake. Here the last of the Laurentian series consists of gray coarse rough-surfaced quartz and mica-rock. The first rock on what is considered to be the Huronian side of the boundary between the two series, consists of highly crystalline dark green hornblende schist, ribboned with fine lines of white quartz grains. It is identical in character with the hornblende schist which is usually found at the base of the Huronian bands in the region to the northwestward of Lake Superior." (*l. c.*, 21, C C.)

It is now necessary to retrace our steps, and give some attention to the Hastings or Montalban series in Canada. To these Mr. Murray called attention in the Report of Progress for 1852–53, remarking: —

> "In Huntingdon, Madoc, Marmora and Belmont, many interesting diversities occur in the Laurentian series, but the rocks belonging to it become so frequently and unexpectedly covered up by projecting and outlying masses of the unconformable fossiliferous formations, in the part investigated, that it is as yet impossible to give any connected view of their arrangement." (*l. c.*, pp. 103–108.)

In the Report of 1863 the rocks were again described (pp. 32, 33), Dr. Hunt giving analyses of the limestone, as belonging to the Laurentian (pp. 592, 593).

In the Report for 1866 (pp. 91–113), the Hastings series was once more discussed by Mr. Thomas Macfarlane, who states that in the previous reports they have been shown to belong to the Laurentian. He remarks that some of the conglomerates are "lithologically not unlike some of the Huronian rocks," but does not appear to have taken ground that this series of rocks was newer than the Laurentian, as Dr. Hunt says he (Maçfarlane) did (Azoic Rocks, p. 170). In the same Report Logan stated that these rocks appeared to be conformable with the Laurentian series, although they might be a higher portion of the series than had been met with elsewhere. (*l. c.*, p. 93.)

In 1867 Dr. Hunt stated that the Hastings series reposed in concordant stratification upon the Laurentian gneiss; but that the Upper Laurentian or Labradorian reposed unconformably, not only on the Lower Laurentian, but also upon the Hastings series. (*Esquisse Géologique d Canada*, pp. 5, 6). The same year Logan held that the "interruption" of a limestone zone in the Hastings series by a labradorite rock (gabbro, norite), supposed to be Upper Laurentian, showed that this zone belonged to the Lower Laurentian. (Quart. Jour. Geol. Soc., 1867, XXIII. 253–257.)

In the same paper Mr. H. G. Vennor gives a section of the Hastings series in ascending order; this is here given, abbreviated by the omission of the descriptive portions.

1. Red felspathic strata.
2. Dark-green chlorite slates.
3. Whitish highly crystalline limestone.
4. Gray silicious or fine micaceous slates.
5. Bluish and greyish mica slates.
6. Grey and pinkish dolomite.
7. Grey micaceous limestone or calc schist.
8. Green diorite-slates.
9. Reddish granitic gneiss.

In the Report of Progress for 1866–69, Mr. Vennor again furnishes a section of the rocks of the Hastings series, referring to the one given above, quoted from the Quarterly Journal of the Geological Society, and using the words "it is here repeated." (*l. c.*, p. 144.)

The following is the section as given, in ascending order, in the Canada Report: —

LOWER DIVISION. A.

1. A great mass of highly crystalline syenitic rock.
2. Reddish and flesh coloured granitic gneiss.
3. Greyish and flesh-coloured gneiss.
4. Crystalline limestone, sometimes magnesian.

MIDDLE DIVISION. B.

1. Hornblendic and pyroxenic rocks.

UPPER DIVISION. C.

1. Crystalline and somewhat granular magnesian limestone.
2. Gray silicious or fine-grained mica-slates.
3. Bluish and grayish micaceous slate
4. Gneissoid micaceous quartzites.
5. Grey micaceous limestone.

Comparison of the sections given by Mr. Vennor will show that there is hardly any resemblance between the two. No one would ever suppose, unless previously informed of the fact, that the same rocks were intended to be embraced in them. Particular notice may be called to the transference of No. 8 of the first section from near its summit to the middle of the series in the second one.

The rocks of Division B, as Mr. Vennor says, were

"seen to rest immediately upon the gneisses, Nos. 2 and 3 of Division A, but whether conformably or not is a question yet to be investigated, as in the localities where they are best represented, the massive diorites and greenstones, which form the base of this division, do not offer any clear marks of stratification."

The rocks of this division were thought to closely resemble the Huronian. Division C contained *Eozoön Canadense*, but no evidence of importance was brought forward to prove its relations to A and B. Overlying all, Trenton limestones were found.

In the Report of Progress for 1870–71, Division A was regarded by Mr. Vennor as Laurentian, and B as probably Huronian. He further states: —

"The dolomites and schists of division C lie unconformably upon the gneiss and crystalline limestones of A, while the true position of the diorites and chloritic schists of division B, appears to be at the base of C; where, however, they are not unfrequently wanting, suggesting a probable unconformity of these both with the upper and lower divisions." C is mentioned as being "seen in contact with the chloritic schists of B, without any apparent unconformity." (*l. c.*, pp. 310, 311.)

In the Report of Progress for 1871–72, Mr. Vennor remarks of Division A: —

"The age of the granite [A], on which these gold-bearing rocks [B] rest, is not yet satisfactorily determined. That it is of more ancient date than the latter, is I think clearly shown by the manner in which they repose upon its flanks, and conform to its general outline. My own conviction is, that this, and other like masses of granite, met throughout the Hastings district, represent eruptions which probably took place towards the close of the Laurentian period, or at some time prior to the deposition of the greenstones, schists, dolomites and limestones of DIVISIONS B. and C." (*l. c.*, p. 130.)

In the Report for 1872–73, Mr. Vennor remarks: —

"The red granites [A] also occur in many localities throughout the area just described, but in a very irregular manner, so as to render it difficult to determine their age in relation to the other rocks. . . . . In the vicinity of the East and West Mountains in Grimsthorpe, they are unstratified, and often appear to be of more recent date than the white mica granites, and even than the diorites of division B." (*l. c.*, p. 140.)

In the Report of Progress for 1874–75, Mr. Vennor groups the rocks of Lanark County as follows: —

I. Mica Schist Group.
II. Dolomite and Slate Group.

III. Diorite and Hornblende Schist Group.
IV. Crystalline Limestone and Hornblende Rock Group.
V. Gneiss and Crystalline Limestone Group.
VI. "Embracing coarse orthoclase gneisses, felsites, garnetiferous gneisses, pyroxenites, crystalline limestones and white quartzo-orthoclase rock."

From its lithological characters he thought it probable that the mica schist group (I.) should be placed near the summit of Division B, and beneath the gray calc-schists and impure limestones of Division C of the Hastings series. He also states that the belt of red gneiss (Division A, Hastings series)

> "separates the mica-schist group (I.) from the dolomite and slate group (II.). It appears to overlie the former, and invariably shows the same constant dip to the south-east and east. But extended observations on its course for a number of miles seem rather to show that its present position is due to an uplift or overturned elevation of an older gneiss series. . . . . The rock is a fine-grained granitic gneiss, composed largely of flesh-coloured feldspar and greyish quartz, and differing in no respect from most of the gneisses heretofore described as Lower Laurentian."

Group V. was found apparently overlying Group IV., the limestone group. It would seem that *Eozoön* had been found in Groups III. and IV. (*l. c.*, pp. 105–165.)

Mr. Selwyn, the next year, in quoting from Mr. Vennor's work, writes: —

> "The geological structure of this section of the country is exceedingly intricate, but when worked out will be both important and instructive. It is now apparent that the rock groups referred to in my last report as I. II. III. and IV., constitute together the lower members of one great crystalline series, while V. and VI., of the same report, constitute its upper members. These groups include the so-called Hastings series of the earlier reports, and the Eozoon has now been found from the lowest to the highest group. . . . . Throughout this region the lowest rock is a massive red, orthoclase gneiss, in which, as a rule, no bedding planes can be recognized, and the groups above enumerated overlie it in, probably unconformable sequence. In many places, in connection with the Bonnechere limestone trough, labradorite rocks were observed, but these appear to be quite conformable with the rest of the series." (Report of Progress, 1875–76, p. 4.)

In the Report of Progress for 1876–77, Mr. Vennor remarks: —

> "Now these rocks represent Division B, and a part of C, of the *Hastings series* which have been compared, by some investigators, to the Huronian, but

which I have now shown are really only the westward extension of the diorites hornblende schists and mica-slates of Lanark and Renfrew counties, or, in other words, of Groups I., II. and III. But these last, as we have also shown, are simply a low portion of the gneiss and limestone series which has always been looked upon as typical Laurentian. Consequently, we are finally led to the important conclusion that the *Hastings series* is not, as it has up to the present been considered, the most recent, but rather the oldest portion of the great system of rocks we have been investigating from the year 1866 to 1875 inclusive. Further, it was clear that this great crystalline, gneiss and limestone series rested upon a still older gneiss series, in which no crystalline limestones had yet been discovered. This series is referred to as Division A in the Report of Progress, 1866–69, where, however, limestones are, incorrectly, mentioned as occurring in it. It . . . . is the rock which may be said to form the back-bone of Eastern Ontario, and the nucleous around which have been deposited all succeeding formations. This, then, is undoubtedly Archæan and Lower Laurentian, and consequently the crystalline limestones and gneisses constitute a series which would come in beneath Sir W. E. Logan's Upper Laurentian or Labradorite series. As regards the existence of this latter as a distinct formation, however, I entertain grave doubts." (*l. c.*, p. 254.)

As a reason for these doubts he points to several localities where he says the labradorite (Norian) rock is interstratified with the limestones of this series, and to others where it is conformable with the Hastings series. Mr. Vennor concludes : —

"So far, then, my investigations in Eastern Ontario show but three great divisions or groups of rocks, namely : —

"1. A great gneissic and syenitic series, without limestones.

"2. A thinner gneissic series with labradorites and limestones.

"3. Lower Silurian (Potsdam to Trenton)." (*l. c.*, p. 277.)

In 1877 Mr. Vennor said (Am. Jour. Sci., 1877, (3) XIV. 313–316) : —

"We find that there still exists a great *Azoic* formation, consisting of syenite and gneiss (?) without crystalline limestones. In this there are but little indications of stratification. Occasionally a limited surface presents an approach to an *obscure stratification*, but this does not appear to be due to the deposition of sediment. This rock forms the back-bone of Canada. On it there has been deposited a great series of gneisses, schists, slates, crystalline limestones and dolomites, which, although heretofore grouped with the former, is clearly distinct and unconformable. . . . . *Eozoon Canadense* belongs undoubtedly in the main to the highest band of crystalline limestone yet found. . . . . I may simply state that I consider both the Huronian and Upper Laurentian of Sir W. E. Logan to belong rightly to my second division, which I must for the present call Upper Laurentian. . . . . I have found Labradorite rocks clearly interstratified with several of my bands of limestone, and I fail entirely to discover Sir William's upper distinct system — yet I have been over the same ground. The *Huronian* and *Hastings series of rocks* I believe to be simply an altered condition, on their westward extension, of the lower portion of my *second system.*"

Retracing our steps, we see that in 1870, under date of December 13, 1869, Dr. Hunt held that the *Eozoön Canadense* of Madoc, and hence the Hastings series, occurred in the Laurentian. (Am. Jour. Sci., 1870, (2) XLIX. 75–78.) Later, under date of May 10, 1870, he referred the Hastings series to the Terranovan, but it would seem that, when the term Terranovan series was first employed by him, it was regarded as being, in part at least, Potsdam. He remarks: —

> "From these investigations of Mr. Murray we learn that between the Laurentian and the Quebec group, there exists a series of several thousand feet of strata, including soft bluish-grey mica-slates and micaceous limestones, belonging to the Potsdam group; besides a great mass of whitish granitoid mica-slates, whose relation to the Potsdam is still uncertain. To the whole of these we may perhaps give the provisional name of the Terranovan series, in allusion to the name Newfoundland." (Am. Jour. Sci., 1870, (2) L. 85, 87, 88.)

To this series he referred the White Mountain rocks, as well as certain rocks in New Brunswick.

In the Twenty-first Annual Report of the Regents of the University of New York, Dr. Hunt remarked of the Hastings series (1871, p. 48): —

> "In the county of Hastings, in the province of Ontario, not less than 21,000 feet of strata, consisting of crystalline schists, limestones and diorites, are found resting conformably upon the Laurentian series."

In a postscript (*l. c.*, p. 98) he states: —

> "More recent researches by the Geological Survey of Canada have shown that the rocks of Hastings county . . . . rest unconformably upon the Laurentian, and belong to one and possibly two distinct systems. The upper and larger portion consists in a great part of mica-schists and micaceous limestones, while at the base are great masses of dioritic and hornblendic schists with iron ore, possibly of Huronian age."

In some remarks of Dr. Hunt, in 1873, it was stated: —

> "As regards the Norian, which had once been joined by the Laurentian, Dr. Hunt had elsewhere shown that we had reason for suspecting that it might be more recent than the Huronian, and possibly than the Montalban, a conclusion which appeared to be confirmed by the facts made known by Hitchcock." (Proc. Bost. Soc. Nat. Hist., 1873, XV. 310.)

In 1875 Dr. Hunt remarked of the White Mountain or Montalban series (Hastings series) : —

> "These ancient rocks are also largely represented in Hastings County, Ont., where they occupy a position between the Laurentian and the fossiliferous limestones of the Trenton group, and are the equivalents of similar limestones and micaceous quartzites in Berkshire County, Mass., and elsewhere in New England." (Proc. Bost. Nat. Hist., 1875, XVII. 509.)

In 1878 Dr. Hunt referred the limestones of the Hastings series to the Lower Taconic (Taconian). (Proc. Bost. Soc. Nat. Hist., 1878, XIX. 278 ; Preface to Second Edition of Chemical Essays, pp. xxii, xxvi.) In the last quoted work the Hastings limestones and slates are said to lie between the Huronian and Trenton. In 1879 the Norian was said by Dr. Hunt to rest unconformably upon the gneisses and crystalline limestones of the Laurentian, and held to be older than the Huronian. The Huronian was also said to rest unconformably on the Laurentian, on the north shores of Lakes Huron and Superior, thus rejecting the positive evidence given by Messrs. Logan and Bell of their conformable relations (in one case underlying however) on the north side of Lake Superior.

The rocks of the Montalban series "are believed to be younger than the Huronian, although some geologists have supposed them to be older." (The Geologist's Travelling Hand-Book, pp. 10–13.) The Taconian in the previous year was said to be found reposing alike on the Laurentian, Huronian, and Montalban, and to be overlain, in apparent unconformity, by the Upper Taconic, which was considered to be identical with the Quebec group of Logan. (Nature, 1878, pp. xviii, 444.)

In the Report of Progress for 1877–78, Mr. Selwyn made some remarks on the Quebec Group and the older Crystalline Rocks of Canada." (A., pp. 1–15.)

He separated the Quebec into three groups.: —

1. The Lower Silurian group.
2. The Volcanic group, probably Lower Cambrian.
3. The Crystalline Schist group. (Huronian ?)

Mr. Selwyn further said : —

> "In any case, I think, there are very few who would agree with Dr. Hunt in the general proposition that the diorites and serpentines of the Quebec group are of sedimentary origin, and the amygdaloids altered argillites ; unless all contemporaneously interbedded volcanic products are to be considered as of sedimentary origin, the Quebec group might be said to present some of the most

marvellous instances on record of '*selective metamorphism.* But whether this is so or not, there seem to be no good grounds for assigning either an age or an origin to the cupriferous diorites, dolerites, and amygdaloids of the Eastern Townships different from that of the almost identical rocks of Lake Superior."

Of the Hastings series he says: —

"The gradual progress of the work, however, from west to east has now, I think, conclusively demonstrated that the Hastings group, together with the somewhat more crystalline limestone and gneiss groups, ... form one great conformable series, and that this series rests quite unconformably on a massive granitoid gneiss."

Of the Norian rocks he said: —

"In not one of the several areas where they are known to occur in Canada, have they yet been mapped in detail, and even their limits, as indicated on the geological map, are more or less conjectural. . . . . Professor Hitchcock shews that they rest unconformably on the upturned edges of the '*Montalban*' gneisses, leading to the conclusion that the gneisses of the White Mountains are older than the 'Norian,' whereas Dr. Hunt, solely, I believe, on mineralogical considerations, supposes these same '*Montalban*' gneisses to constitute a system newer than the Huronian. Here, then, as in the Hastings region, we find theory and experience at variance. . . . . If it is admitted — which, in view of the usual associations of Labrador feldspars, is the most probable supposition — that these anorthosite rocks represent the volcanic and intrusive rocks of the Laurentian period, then also their often massive and irregular, and sometimes bedded character, and their occasionally interrupting and cutting off some of the limestone bands, as described by Sir W. E. Logan, is readily understood by one who has studied the stratigraphical relations of contemporaneous volcanic and sedimentary strata, of palæozoic, mesozoic, tertiary and recent periods. Chemical and microscopical investigation both seem to point very closely to this as the true explanation of their origin. That they are eruptive rocks is held by nearly all geologists who have carefully studied their stratigraphical relations. . . . . When we recall the names of Dahl, Kerulf and Torrell in Norway, Maculloch and Geike in Scotland, Emmons, Kerr, Hitchcock, Arnold Hague, and others in America, all of whom consider these norites as of eruptive origin, we may well pause before accepting Dr. Hunt's conclusions respecting them, and that they should often appear as 'bedded metamorphic rocks,' . . . . is quite as probable as that we should find the mineralogically similar dolerites occuring in dykes and bosses, and in vast beds interstratified with ordinary sedimentary deposits of clay, sand, etc., as we do over wide areas in Australia and elsewhere. In conclusion, I may say that I fail to see that any useful purpose is accomplished, in the present stage of our knowledge of the stratigraphical relations of the great groups of rocks which underlie the lowest known Silurian or Cambrian formations, by the introduction of a number of new names such as those proposed by Dr.

Hunt for systems which are entirely theoretical, in which category we may in my opinion include the Norian, Montalban, Taconian and Keeweenian. These, one and all, so far as known, are simply groups of strata which occupy the same geological interval, and present no greater differences in their physical and mineralogical characters than are commonly observed to occur both in formations of the same epoch in widely separated regions, and when physical accidents, such as contemporaneous volcanic action or subsequent metamorphism have locally affected the general character and aspect of the formation within limited areas. . . . . Unfortunately in Canadian geology, hitherto, stratigraphy has been made subordinate to mineralogy and palæontology, and, as the result, we find groups of strata which the labours of the field geologists during the past ten years have now shewn all to occupy a place between Laurentian and Cambrian, assigned to Carboniferous and Upper Silurian in New Brunswick and Nova Scotia, to the peculiar palæontological Lévis group and its subdivision, Lauzon and Sillery, in the Eastern Townships, and to Lower and Upper Laurentian, Huronian, Lower Silurian and Triassic on the north side of the St. Lawrence valley and around Lake Superior. The same system of mineralogical stratigraphy is now further complicating and confusing the already quite sufficiently intricate problem by the introduction of the new nomenclature I have referred to, and in some cases these names are applied regardless of and in direct opposition to well ascertained stratigraphical facts. A similar unfortunate instance of palæontological stratigraphy is found in the history of the Quebec group ; and especially in the late introduction in it of the belt of supposed Potsdam rocks, about which I have already stated my opinion. In the reconstruction of the geological map of Eastern Canada, — and in this I include the country from Lake Winnipeg to Cape Breton and Labrador, — rendered necessary by the present state of our knowledge, I should propose to adopt the following divisions of systems to include the groups enumerated : —

" I. Laurentian :

" To be confined to all those clearly lower unconformable granitoid or syenitic gneisses in which we never find interstratified bands of calcareous, argillaceous, arenaceous and conglomeratic rocks.

" II. Huronian :

" To include — 1. The typical or original Huronian of Lake Superior and the conformably — or unconformably, as the case may be — overlying upper copper bearing rocks.

" 2. The Hastings, Templeton, Buckingham, Grenville and Randon crystalline limestone series.

" 3. The supposed Upper Laurentian or Norian.

" 4. The altered Quebec group, as shewn on the map now exhibited, and certain areas not yet defined between Lake Matapedia and Cape Maguereau in Gaspé.

" The Cape Breton, Nova Scotia and New Brunswick pre-Primordial subcrystalline and gneissoid groups.

"III. CAMBRIAN:

"In many of the areas, especially the western ones, the base of this is well-defined by unconformity, but in the Eastern Townships and in some parts of Nova Scotia it has yet to be determined. The limit between it and Lower Silurian is debatable ground, upon which we need not enter. . . . . One point I wish particularly to insist on is, that great local unconformities and lithological differences may exist without indicating any important difference in age, especially in regions of mixed volcanic and sedimentary strata, and that the fact of crystalline rocks (greenstones, diorites, dolerites, felsites, norites, &c.,) appearing as stratified masses and passing into schistose rocks, is no proof of their not being of eruptive or volcanic origin — their present metamorphic or altered character is, as the name implies, a secondary phase of their existence, and is unconnected with their origin or original formation at the surface, but is due partly to original differences of composition and partly to the varying physical accidents to which they have, since their formation, respectively been subjected." (*l. c.*, pp. 1–15 A.)

Mr. Selwyn's views were discussed, and in part objected to, by Mr. Thomas Macfarlane. (Canadian Naturalist, 1879, (2) IX. 91–103.)

Dr. Hunt very ingeniously derives comfort from the preceding paper by ignoring most of it and claiming: —

"The pre-Cambrian age of these crystalline schists in Eastern Canada has now been clearly proved by the . . . . recent stratigraphical studies of Selwyn, as announced by him in 1878." (Proc. Am. Assoc. Adv. Sci., 1879, XXVIII. 286.)

In 1879 Dr. Dawson remarked that

"the idea that the Middle Laurentian, the horizon of Eozoon Canadense and of the great Phosphate and Graphite deposits, is identical with the Hastings group, or with the Huronian, has, I am fully convinced, after some study of the Lake Huron, Madoc and St. John exposures of these formations, no foundation in fact." (Canadian Nat., 1879, (2) IX. 180.)

Dr. Dawson, however, gave no proof of this statement, while Mr. Vennor had worked out the subject according to the stratigraphical methods of the Canadian Survey, — a labor of ten years; this is better than an unsupported assertion.

NEW BRUNSWICK.

In this Province it is not necessary to go back in the geological history earlier than the first edition of Principal J. W. Dawson's Acadian Geology, for in his writings and those of Messrs. Bailey and Matthew nearly all the evidence bearing on our subject is to be found. The methods of work appear to be the same as those of the Canadian Survey, and therefore similar results were to be expected.

In 1855 Dr. J. W. Dawson, on lithological grounds, would have referred the rocks in the vicinity of St. John to the Lower Carboniferous; but on account of the statement of Dr. Gesner, that similar rocks underlie the Carboniferous sandstones, he says, "I must be content in the mean time to consider them as silurian rocks of uncertain age." (Acadian Geology, 1st ed., p. 324.)

Later he states regarding these rocks : —

> "The limestone and its associated shales underlie unconformably the Lower Carboniferous conglomerate. . . . . This arrangement is general throughout the belt to which the St. John rocks belong. The whole of the beds of the St. John group, appear to be conformable to one another, and to constitute one formation." (Canadian Nat. and Geol., 1861, (1) VI. 164.)

From the resemblance of these rocks to the Devonian of Gaspé, and from the plants found in them, he considers them all to be of that age.

Later he writes regarding this entire series of rocks : —

> "The Devonian age of the upper members of this great series of beds I regard as established by their fossils, taken in connexion with the unconformable superposition of the Lower Carboniferous conglomerate. The age of the lower members is less certain. They may either represent the Middle and Lower Devonian, or may be in part of Silurian age." (Quart. Jour. Geol. Soc., 1862, XVIII. 303.)

In the later editions of this Acadian Geology (1868, 1878), he follows in the main Messrs. Bailey and Matthew; therefore we need only incidentally refer to those editions.

Mr. Geo. F. Matthew, in 1863 (Canadian Naturalist, 1863, (1) VIII. 241–260), divided the rocks at St. John into the following groups : —

> "1st Portland Series containing fragments of plants in the upper beds; 2d, Coldbrook Group; 3d, St. John Group, containing lingula, a conchifer,

annelides, and coprolites ; 4th, Bloomsbury Group ; 5th, Little River Group, containing numerous plants, several crustaceans, and wings of insects, etc. ; 6th, Mispeck Group." (*l. c.*, pp. 244, 245.)

He states that no proof has been observed that the St. John group is unconformable with either the overlying or underlying rocks. (*l. c.*, p. 247.) The Mispeck group is said to contain fragments like the lower slates of the Coldbrook group. (*l. c.*, p. 253.) The rocks in the vicinity of Black River, to which the name Coastal group was afterwards given, were here classed under the Little River group. This group was divided into two parts, the lower called the Dadoxylon sandstone, and the upper the Cordaite shales. He says it seems clear that the Black River rocks mentioned above

> "form a part of the Upper Devonian series, because, — 1st They overlie the Dadoxylon sandstone conformably (or nearly so). 2nd They underlie carboniferous deposits unconformably. 3rd They partake of the flexures of the Devonian series, which preceeded the formation of the Lower Carboniferous conglomerate. . . . . I have connected them with the cordaite shales, but it is quite possible that the upper part may be altered beds of the Mispeck group." (*l. c.*, pp. 252, 253, 256–258.)

Mr. Matthew's statements regarding the age of the entire series are far from being clear. In some places he appears to regard them as Devonian, in others as being in part Devonian and in part Silurian. His language admits of no other interpretation than that he regarded the Coldbrook group as being of Devonian age. (*l. c.*, pp. 258, 259.)

In 1865 the same geologist referred the Portland series to the Laurentian and the Coldbrook group to the Huronian. The Coldbrook rocks were placed in two divisions, a lower and an upper. The upper division is said to be "largely composed of erupted materials, diorites, tufas, and volcanic mud," the same as the Huronian of Canada, and to be "*conformably* surmounted by the lowermost strata of the Lower Silurian formation."

He further remarks : —

> "Considering, therefore, the origin of these deposits as well as their position relative to the more ancient series and the Lower Silurian beds above, we have little hesitation, notwithstanding that the latter are conformable to them, in assigning these semivolcanic sediments to the 'Huronian series' of Logan."

The St. John group was regarded by him as being the equivalent of the Potsdam, Calciferous, and possibly Chazy formations.

A series of rocks which cover an area of about seventy miles long and twenty wide, stretching northeastwardly from Passamaquoddy Bay, and including the highest eminences in the southern counties, was assigned to the Upper Silurian. The Bloomsbury, Little River, and Mispeck groups were placed in the Middle and Upper Devonian, and were said to rest unconformably upon the Laurentian, Huronian, Lower Silurian, and Upper Silurian strata, and it was stated that the Primordial shales appear to overlie the Huronian without any appreciable discordance between the two. (Quart. Jour. Geol. Soc., 1865, XXI. 422–434.)

In Messrs. Bailey, Matthew, and Hartt's "Observations on the Geology of Southern New Brunswick," 1865, a work prepared for the press by Prof. Bailey, the rocks referred to the Huronian and Laurentian ages are so placed on theoretical and lithological grounds. Regarding the age of the Portland group, here assigned to the Laurentian, he writes : —

> "It might readily be supposed that the extreme metamorphism exhibited by the rocks of the Portland Group would be accepted as conclusive evidence of their great antiquity. Indeed the fact of such antiquity could scarcely have been doubted, were it not for the intimate association and almost entire conformability between the beds of this and the overlying groups, which have heretofore induced all the observers who have examined the district to link them in a single series. As the latter are unquestionably of Upper Devonian age, the beds of Portland were supposed to represent either a portion of the Lower division of the same formation, or possibly the upper part of the Silurian." (*l. c.*, p. 18.)

The reasons for assigning it to the Laurentian are, in brief, partly lithological, and partly because it seemed to them probable that the Coldbrook group was Huronian, and therefore the syenites (Portland group) must be Laurentian. (*l. c.*, p. 18.) Between the Coldbrook group and the underlying syenite and limestone, Prof. Bailey states that Mr. Matthew observed "evidence of slight unconformability." (*l. c.*, p. 49.) Again he remarks : —

> "During the deposition of the various rocks referred to the Azoic and Silurian Ages, a prolonged period of repose prevailed throughout the districts where these rocks occur, broken only by the volcanic activity which marked the epoch of the Coldbrook Group. . . . . Through all these vast intervals of time no evidence exists to show that any violent disturbances broke the general quiet, unless it be the folding of the Portland and Kingston rocks, and even this may have been the result of a later date. Each formation was quietly deposited upon that which preceded it, the almost entire conformability which now marks their succession being conclusive evidence that no period of marked upheaval prevailed between the deposits of one epoch and those of another." (*l. c.*, p. 50.)

Of the Bloomsbury group, which later was united to the Coldbrook group, he states : —

> "The association of the Bloomsbury rocks with the Groups which are to follow, is conclusively proved by the general similarity of their deposits, by their entire conformability, and the *absence* of such perfect conformability between these and the Primordial (or Saint John) rocks below. As the overlying beds have been shown to be unquestionably of Upper Devonian age, there can be no hesitation in referring the Bloomsbury Group to the same horizon." (*l. c.*, p. 53.)

The Coldbrook group, while nominally underlying the St. John group, was found in another place overlying it. In this locality it seems that the rocks were recognized as Coldbrook (Huronian) from lithological characters, and their stratigraphical position explained by a reversed folding. (*l. c.*, pp. 23, 28, 29.)

In regard to the age of the Kingston group, which with the Mica Schist formation appears to be the Upper Silurian of Matthew, it is said : —

> "We have only the general lithological characters and the stratigraphical relations upon which to rely for the determination of this important question. As the conclusions derived from these two independent sources accord exactly, we may consider the position of this formation as established with some degree of certainty." (*l. c.*, p. 38.)

Again he states, quoting from Mr. Matthew : —

> "Their relations to other groups, as well as their appearance when altered, indicate that the Kingston rocks and their associates may be provisionally looked upon as Upper Silurian, though Middle Silurian and Lower Devonian beds may also occur. The only objection to this view is the absence of such hard rocks along the outcrops of the soft Lower Silurian strata in Saint John County, where these latter are covered by deposits of Upper Devonian age. This may be accounted for by denudation subsequent to their deposition, or by supposing an elevation of the older rocks above the sea when those of Kingston were being formed." (*l. c.*, p. 39.)

The arrangement of the formations in this report, it has been seen from the above, is as follows : —

LAURENTIAN. The Portland group, if it is not Huronian, doubt existing.
HURONIAN. Coldbrook group, probably.
POTSDAM AND QUEBEC. St. John group.
UPPER SILURIAN. { The Kingston group.
Limestones of Dalhousie.

LOWER DEVONIAN.	Possibly some portion of the Kingston group.
UPPER DEVONIAN.	Mispeck group. Little River group. Bloomsbury group.

In a paper presented to the American Association for the Advancement of Science (1869, XVIII. 179–195) by Messrs. Bailey and Matthew, it is remarked that "several hills of crystalline felspar rock, associated with hypersthene," were, on the authority of Dr. Hunt, referred to the Labrador or Upper Laurentian series. (*l. c.*, p. 181.) The Kingston series the authors were inclined to regard as Upper Silurian and Devonian. The overlying formations below the Carboniferous, excepting in their subdivisions, and being classed as Siluro-Devonian, remained about as in 1865. This paper was revised up to April, 1870.

In a joint report by Messrs. L. W. Bailey and G. F. Matthew (Geology of Canada, Report of Progress, 1870–71, pp. 13–240) numerous changes were made in the supposed sequence of the formations, Dr. Hunt having worked in the field with them. Lithological evidence had been thought sufficient authority for enlarging the amount of Laurentian rocks; and the finding of a few pebbles in some of the granitoid masses was regarded as proof that they were altered conglomerates.

The rocks referred, on lithological evidence, to the Huronian, were divided into three groups: the Coldbrook, Coastal, and Kingston. The former was found in some places to overlie the Primordial or St. John group, and to conformably underlie rocks of Devonian age, to which age these rocks (the Bloomsbury group) had formerly been referred. However, lithological characters being then regarded as more weighty than stratigraphical ones, this difficulty, together with some others, was surmounted in the following manner.

> "Prior to the work of the present survey, the river St. John, at the Suspension bridge, was considered as marking the extreme western limit of the Huronian rocks of St. John County, the only sediments noticed to the westward of this point, which bore much resemblance to them, being supposed, on stratigraphical grounds, to be more recent. . . . . Recent observations, however, have led us to the conclusion that a part of these supposed more recent sediments are in reality the Huronian strata brought up by a fold, and by an overturn of the whole series made to rest upon newer strata. . . . . The diorites and schists of Bloomsbury Mountain, although apparently resting upon the slates of the St. John group, and overlaid by Devonian sandstones, which conform to them in dip and strike, are now also regarded as Huronian strata. . . . . On both sides of Musquash Harbor a series of hard green epidotic subcrystalline schists, sometimes with dark green serpentine, may be seen resting

upon black carbonaceous crumbling shales. . . . . These latter dark colored rocks resemble very closely some portions of the St. John group as seen in the city of St. John, and are supposed to be continuous with them through a belt of similar rocks, extending across the peninsula of Pisarinco, and coming out at Mill Creek in Pisarinco Harbor. In this view, it is probable that the structure indicated in this group at St. John, and to be presently noticed, will hold good here also, viz.: That the St. John group is inverted upon itself, and that the green crystalline schists, though overlying that group, are in reality more ancient and probably of Huronian age." (*l. c.*, p. 60.)

Of the Huronian rocks at Ratcliffe's mill-stream it is stated that

"they overlie the Primordial strata, both formations occupying a nearly vertical position, with a slight southward inclination, and both being inverted." (*l. c.*, p. 63.)

Of the Bloomsbury group it is again remarked: —

"In our earlier publication, this hill . . . . has been referred, from the fact of its overlying the slates of the St. John group, to the Devonian series; but the close resemblance in aspect borne by the rocks composing it to those so largely developed to the north and north east, from which they are separated only by a narrow valley, renders it more probable that the great mass of strata in this hill is of Huronian age, and that, though here apparently resting upon the Primordial strata (which in the valley alluded to dip southerly under Bloomsbury Mountain) they are in reality more ancient than these latter, and are here brought up along a line of fault in a similar manner to those of Ratcliffe's millstream." (*l. c.*, pp. 63, 64.)

The upper part of the Coldbrook group, from its conformably underlying at other places the St. John group, and from its containing pebbles supposed to have been derived from the lower portion of the Coldbrook group, was regarded as forming the base of the Primordial or St. John group, (*l. c.*, p. 59,) an unfossiliferous portion of the latter. As we have seen before, part of the Coldbrook group was found resting on the St. John group; the latter was supposed to have been inverted upon itself, which would explain the fact that Huronian rocks were overlying Primordial ones. (*l. c.*, pp. 136–139.)

Of the rocks of the Coastal group it is said that they

"have been found to overlie, at several points, strata of Upper Silurian and Lower Devonian age. Hence, those occurring along the coast were, in our report on the geology of Southern New Brunswick, described in connection with the Devonian rocks of St. John County, under the denomination of the Coastal group, Dr. Hunt, however, who has examined a large number of specimens collected from these rocks, and has visited a part of the districts in which they occur, is of opinion that their lithological aspect is such as to indicate much greater antiquity. In the presence of diorites, felsites and other crystalline rocks, he finds this series to resemble the Huronian strata of St. John County. Portions of it do indeed correspond in the appearance of the beds to the Huronian of that county, but the series of the coast is much more voluminous than the resembling parts of the Coldbrook group, and contains conglomerates, limestones, micaceous slates, feldspathic grits, etc., which have not been recognized among the Huronian rocks of St. John County, first described as the Coldbrook group." (*l. c.*, p. 83.)

In this connection it may be well to remember that later Dr. Hunt acknowledged that at that time his "opportunities for studying the Huronian had been very imperfect."

Again Messrs. Bailey and Matthew say: —

> "These Devonian sediments appear to dip beneath those of the Coastal type at those points where the two have been observed together, but, as the latter are lithologically unlike those of the Devonian series, and do strongly resemble those elsewhere referred to the Coastal group, we suppose that the appearance alluded to is due to a dislocation." (*l. c.*, p. 94.)

Again, of the Coastal rocks in another locality: —

> "Their superposition on the Dadoxylon sandstone, however, being probably the result of a fault and overlap, they are considered as pertaining to the same horizon with the strata already described along the coast westward of St. John, and in Charlotte County, to which the designation of the Coastal group has been given." (*l. c.*, p. 98.)

It is also stated that, although Upper Silurian strata were found "intercalated with the Kingston rocks, the intimate association of the two is evidently accidental"; hence the Kingston rocks are Huronian, especially as the Coastal group overlies them. How the "accidental intercalation" could occur between Huronian and Upper Silurian rocks is not explained.

We thus see that, while the Portland group remains in the Laurentian, the Bloomsbury group, formerly regarded as Upper Devonian, is placed in the Lower Coldbrook group; the Coldbrook group divided into two portions, and the upper one assigned to the St. John group; the Kingston group taken from the Upper Silurian and Lower Devonian, and placed above the Lower Coldbrook in the Huronian; and the Coastal group formed from part of the Little River group of the Upper Devonian and placed in the Huronian above the Kingston group.

In this way two groups of rocks are intercalated between the two members of the Coldbrook group. It is necessary to remember, while observing this extraordinary rearrangement of the rocks in Southern New Brunswick, throwing them from 8,000 to 15,000 feet perpendicular, that it has been stated all along that the Azoic and Silurian ages were ages of stability and repose, excepting some volcanic action, and that the formations were conformable to one another, with the possible exception of a slight unconformability between the Portland and Coldbrook groups. It would seem, then, that lithological resemblances — especially if accompanied by the dictum of Dr. Hunt — were regarded as being more important than stratigraphical facts. There does not appear to be any evidence of faults or overturns; but these were imagined in order to explain the resemblance in lithological characters, and carry out the views of the Canadian geologists. The language of Messrs. Bailey and Matthew admits of no other possible construction.

The natural explanation of the lithological resemblances seems to us to be, that similar eruptive materials were originated in different ages. Such faults and overturns should by no means have been introduced, unless some evidence could be brought forward of their actual existence.

In the Report of Progress for 1876–77, Mr. Matthew regards the Coastal group as Laurentian, and the Kingston group as partly Upper and partly Lower Silurian. At one place this group is said to unconformably overlie the St. John group, and to contain pebbles probably derived from it. (*l. c.*, pp. 334-350.)

In the Report of Progress for 1876–78, the Kingston series is regarded by the same gentleman as Upper Silurian on account of palæontological evidence, although lithologically it appears to be Huronian, and to dip beneath that group. (*l. c.*, p. 6 E.)

In Prof. Bailey's report, in the same volume, the Coldbrook and Coastal groups remain in the Huronian, and the Upper Coldbrook series is taken away from the St. John group, and replaced in the Huronian below the Coastal, on account of the unconformability of certain rocks supposed to belong to the series. (*l. c.*, pp. 28, 29 DD.)

The Huronian is conformably interbanded with the Devonian rocks at Bloomsbury Mountain and westward from Black River; but that this does not prove that they belong to the same series is said to be shown by the conglomerates of the Devonian being largely made up of *débris* from the Huronian, and by the absence of conformability in some places. It would seem that in much of the district in question Prof. Bailey has no other than lithological evidence to prove that he is dealing with Devonian strata. (*l. c.*, pp. 21–23 DD.) The statement that the Devonian conglomerates contain pebbles from the Huronian could only be accepted after a careful examination of the rocks in question by a competent lithologist.

Mr. R. W. Ells, in the same volume, describes some Huronian and Laurentian rocks, claiming that they are unconformable, and that "in many places a gradual transition can be traced from the green slates through schists, felsites and gneisses to the syenites." (*l. c.*, p. 4 DD.) No evidence is advanced to prove either statement; and in regard to the latter one it is to be wished that some of the places where these phenomena can be seen might be pointed out, so that the actual existence of such a transition might be demonstrated. The rocks described by Mr. Ells as Laurentian and Huronian were in 1865 assigned to the Devonian, but in 1871, under the divisions of Coldbrook, Coastal, and Kingston, were included in the Huronian by Messrs. Bailey and Matthew.

In the Report on the Geology of Canada for 1878–79 is a contribution by Messrs. Bailey, Matthew, and Ells. In this the Laurentian or Portland rocks are divided into two groups, one of which is regarded as being more recent than the other, but no proof of this is given. The Coldbrook, Coastal, and Kingston groups were placed in the Huronian. No instance was observed of the Coldbrook resting upon the Laurentian; but as the Coastal lies upon the Coldbrook and the Laurentian, there was thought to be no reasonable doubt as to the true succession. The Coastal was also said to contain fragments of the Coldbrook in it. The Kingston was replaced in the Huronian, because beds containing Upper Silurian fossils were found to abut against those rocks, instead of forming a continuous series. The St. John group was placed in the Cambrian, while in the Cambro-Silurian were included rocks which in 1871 were described as Laurentian, etc.

In a paper read before the American Association the Advancement of Science, August, 1880, Prof. Bailey remarked:—

> "Beginning with the older formations, we have found no reason to depart from the view first advanced by us, that, beneath the fossiliferous rocks of the St. John or Acadian Group, there exist two, if not three distinct formations, equivalent in part, at least, to the so-called Laurentian and Huronian formations in other parts of Canada. It has been objected that this reference has been based upon the wholly valueless ground of lithological characteristics, and that the strata in question, being destitute of fossils, may even be Silurian; but such objection entirely ignores the fact that, accompanying such differences of lithological character, there is, at the same time, the most marked evidence of unconformability. A study of the Primordial rocks east of St. John, in

1879, placed this point beyond question, they having been then found by me to occupy irregular troughs in the older Pre-Silurian rocks, resting sometimes upon one and sometimes upon another of the subdivisions of the latter, crossing their strike obliquely, and having at their base coarse conglomerates made up of the waste of the underlying formations. The latter being thus unquestionably of Pre-Silurian age, it is equally obvious that in their vast thickness, in the markedly different conditions under which their several divisions were accumulated, and finally in the further unconformability indicated between these divisions, they represent a vast interval of time, and are at least as old as the Huronian and portions of the Laurentian system, which in all their physical characters they so nearly resemble. No more marked coördination of distant formations could be desired than is here furnished between the great mass of coarse gneisses at the base of the series, associated with finer gneisses, quartzites, graphitic and serpentinous limestones and dolomites (the probable equivalents of the Hastings' series of Mr. Vennor), and capped by the great volcanic series of the Huronian, with its petrosilicious and felsitic strata, ash-rocks and agglomerates, the whole unconformably traversed by bands of the lowest Cambro-Silurian, and the similar succession observed about Lake Huron and elsewhere. . . . . It should be added in this connection that in the rocks here assigned to the Huronian, there are as a whole two well-marked divisions, the lower (or Coldbrook group) consisting almost entirely of fine grained felsitic strata, with diorites, amygdaloids and porphyries, and the upper (or Coastal group) of schistose rocks, often talcoid or nacreous, with conglomerates and limestones and holding ores of copper, and that between the two there is not unfrequently evidence of at least a partial unconformability, but in general the relations to each other are much more intimate than are their relations either to the underlying Laurentian, or to the Primordial strata which overlie them." (*l. c.*, pp. 416, 417.)

In this paper the Kingston was separated by Prof. Bailey into two groups : one of these was placed in the Huronian, and the other in the Lower Silurian. This author further states, that the Upper Silurian

"age can now be definitely assigned to the very remarkable group of rocks surrounding Passamaquoddy Bay, and which include the peculiar orthophyres or felspar-porphyries of Eastport and Pembroke, Me., these latter having been found to rest directly and almost horizontally upon a series of fossiliferous sandstones, identical with those which at the last-named locality have been long known to contain a rich Upper Silurian fauna. Another instance of the difficulty of distinguishing the rocks of this most variable formation is to be found in the occurrence, first observed by Mr. Matthew, of corals and other Silurian organic remains on the Long Reach of the St. John River, in amygdaloidal ash-rocks, which are undistinguishable lithologically from those of the Huronian formation, and which, like those of Passamaquoddy Bay, had previously been referred to this horizon." (*l. c.*, p. 421.)

The relation of the rocks as given by the preceding writers has been given so far as we are able to make it out in the table appended.

In 1878 Dr. T. Sterry Hunt remarked: —

"In a paper on the Geology of St. John County, New Brunswick, published in the Canadian Naturalist in 1863, and reprinted in part in the geological report of Canada for 1870–71, page 23, Mr. George F. Matthew described, under the name of the Coldbrook group, a great mass of crystalline strata found in southern New Brunswick, to the east of the river St. John. These rocks repose on the Laurentian, and underlie unconformably the uncrystalline Lower Cambrian slates of the city of St. John, which include, near their base, conglomerates holding fragments of the Coldbrook group. From this, and from their lithological characters, these older rocks were, by Matthew, referred soon after to the Huronian series. (Quar. Jour. Geol. Soc., Nov., 1865.) They have since been found to rest unconformably upon the Laurentian, pebbles of which are contained in the conglomerates of the Coldbrook group. In the paper which contained his account of the Coldbrook group, in 1863, Mr. Matthew described a second belt of crystalline rocks similar to these, to which he gave the name of the Bloomsbury group. These, apparently resting upon the Menevian, and conformably overlaid by the fossiliferous Devonian sandstones of St. John, were, at that time, called by him altered Devonian strata. In 1869 and 1870, however, the writer devoted some weeks, in connection with Prof. L. W. Bailey and Mr. Matthew, to the investigation of the geology of southern New Brunswick, when it appeared that the Bloomsbury rocks were but a repetition of the Coldbrook group on the opposite side of a closely folded synclinal holding Lower Cambrian sediments. Accordingly, in the geological report of the gentleman just named, both of these belts were designated as Huronian; in which were now also included two other subdivisions of crystalline rocks found in that region, and previously designated the Coastal and Kingston groups. (Report of Geol. Sur., 1870–71, pages 27, 60, 64.) These Huronian rocks were traced in 1869 and 1870 along the southern coast of New Brunswick, from the head of the Bay of Fundy to the confines of Maine, as was stated by the writer in July, 1870, when these rocks 'called Cambrian and Huronian by Mr. Matthew,' and characterized by the occurrence of diorites and quartziferous feldspar-porphyries, were said to occur in Eastport, Maine, and in Newbury, Salem, Lynn and Marblehead, Massachusetts. (Amer. Jour. Science, II. 1, 89.)" (Azoic Rocks, 1878, pp. 188, 189.)

It would seem that Dr. Hunt's memory must have been at fault, since the views of Messrs. Matthew and Bailey are indiscriminately mingled with his own, while the sequence of time at which these views were presented is generally disregarded. We cannot find, in either of the papers of Mr. Matthew to which Dr. Hunt refers, any evidence that the St. John rocks unconformably overlie the Coldbrook rocks, or that the former contain pebbles derived from the latter. Mr. Matthew expressly states that there is no proof of unconformability,* and also that the deposits of the St. John group

> "present a marked contrast with those of the formation on which they rest [Coldbrook Group]. Coarse fragmental beds and volcanic products are common in the latter; but among the former no conglomerate or even a grit has been detected, or any evidence of synchronic igneous action." (Quar. Jour. Geol. Soc., 1865, XXI. p. 427.)

It is also stated in the Observations on the Geology of Southern New Brunswick (1865, p. 46), that

> "between the rocks above alluded to as constituting the upper member of the Coldbrook Group, and the deposits which underlie the City of Saint John, the contrast is very marked. While in the former, beds of coarse materials are almost universal, the Saint John Group is, without exception, a collection of the finer sediments. Throughout the limits of its distribution, not one conglomerate or even a grit has been yet observed; while the sandstones which occur interstratified with the slates, are usually of a fine and even texture."

If there were no conglomerates, or even grits, known in 1865 in the St. John group, and the two formations were conformable, how could Mr. Matthew, in the same paper in which these facts are stated, have referred the Coldbrook group to the Huronian, because it was unconformably overlain by the St. John group, and held fragments of the Coldbrook group in its conglomerates? The fact is, that Mr. Matthew, at that time, assigned the Coldbrook group to the Huronian, on account of its lithological characters, and because it underlaid conformably the St. John group. In fact Dr. Hunt himself was not aware of any such unconformability of the rocks in question, since he thus expressed himself in 1866, referring to the Lower Silurian:—

> "The lowest member of the series as yet known, is a group of 3000 feet of black shales and sandstones, which at St. Johns, New Brunswick, is found resting conformably upon still older schistose rocks, as yet unstudied. This, which has been provisionally called the St. Johns group, has yielded numerous fossils, which have been examined by Mr. Hartt, and show the formation to correspond with the third division (Etage C) of the primordial zone." (Geol. of Canada, 1866, pp. 235, 236.)

Lithological evidence, so far as we can find, is all that is offered in support of the statement that the Bloomsbury group is "a repetition of the Coldbrook group on the opposite side of a closely folded synclinal holding Lower Cambrian sediments." The *synclinal*, the *repetition*, the *faults and overturns*, appear to be purely theoretical, and introduced to obtain conformity with that which the lithological characters seemed to demand. Had not these rocks resembled the Huronian, no one would have ever thought that they were not Devonian; but here appeared to be some discrepancy in the theory of Delesse and David Forbes, adopted by Dr. Hunt, that certain rocks could have appeared only at one epoch in the earth's history, and to get over this difficulty an overturn of the strata was claimed. The "quartziferous feldspar-porphyries" of Eastport, which Dr. Hunt has here placed under the Huronian, have since been shown by Bailey to be at least as recent as the Upper Silurian, since they rest nearly horizontally upon Upper Silurian fossiliferous sandstone. In fact, on comparing Dr. Hunt's published views in 1870 with his explanation of them since given, it becomes quite impossible to make out what those views really were.

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* See Dawson's Acadian Geology, edition of 1868, pp. 660, 662.

In 1870 the Coldbrook group, to which he assigned the felsites, was spoken of as Cambrian. (Am. Jour. Sci., 1870, (2) L. p. 89.) This paper related principally to the Terranovan, since called Montalban, and later separated into the Montalban and Taconian. The Terranovan at that time was regarded by Dr. Hunt as being in part Potsdam, and its relations to the felsites unknown. In 1871, in his address before the American Association (Proceedings, XX. p. 33), Dr. Hunt claimed that in the above-quoted paper of 1870 he held that the Terranovan was more recent than the Huronian. In 1872, in his "History of the Names Cambrian and Silurian in Geology," he claims to have held, since 1870, that the Terranovan (Montalban) and Huronian were pre-Cambrian in age, and refers to the same paper for proof of this. (Canadian Nat., 1872, (2) VI. p. 435.) In his "Azoic Rocks" (pp. 189–193) he claims to have held since 1870, referring to the same paper, that the felsites of Passamaquoddy Bay were Huronian.

According then to the original paper, and to Dr. Hunt's subsequent explanation of it, he maintained in 1870, in the same paper, that

THE FELSITES WERE CAMBRIAN.

THE FELSITES WERE HURONIAN.

THE HURONIAN WAS PRE-CAMBRIAN.

THE TERRANOVAN WAS POST-HURONIAN.

THE TERRANOVAN WAS PRE-CAMBRIAN.

THE TERRANOVAN WAS IN PART (SEVERAL THOUSAND FEET) POTSDAM.

THE GEOLOGICAL RELATIONS OF THE TERRANOVAN TO THE FELSITES WERE UNKNOWN.

From this table of conflicting views the student of North American geology can draw his own conclusions as to the value of the work done on a basis of lithological classification and speculation.

The statements previously given in Dr. Hunt's "Azoic Rocks," in regard to the geology of New Brunswick, were repeated in essentially the same form in 1879 (Proc. Am. Assoc. Adv. Sci., XXVIII. pp. 285–287; Am. Jour. Sci., 1880, (3) XIX. pp. 273–275), together with this remark regarding the lower and upper divisions of the Coldbrook group : —

> "In a joint report of Matthews and Bailey in 1865, these rocks were declared to be overlaid unconformably by the slates in which Hartt had made known a Lower Cambrian (Menevian) fauna, and were compared with the Huronian of Canada."

This again is in part incorrect ; for if Messrs. Bailey and Matthew declared anything in 1865, it was that the St. John group was conformable with the Coldbrook group, or nearly so, and they are so represented in their sections.* Furthermore, in Matthew's paper, published in 1865 (Quart. Jour. Geol. Soc., XXI. p. 425), the St. John group is said to conformably overlie the upper division of the Coldbrook group, and this same statement is made in the Report of Progress of the Canada Geological Survey (1870–71, pp. 59, 136).

Dr. Hunt, in 1873, remarked concerning the work of himself and Messrs. Bailey and Matthew, that he regarded the ancient crystalline rocks in Southern New Brunswick

> "as for the most part the equivalents of the Green Mountain and White Mountain series, or what he calls Huronian and Montalban. These are penetrated by granites, and associated in one part with Norian rocks, but the presence of Laurentian in the region is somewhat doubtful." (Proc. Am. Assoc. Adv. Sci. 1873, XXII., B., pp. 116, 117.)

In 1875 it appears that Dr. Hunt held that the limestones in the vicinity of St. John were of Montalban age. (Proc. Bost. Soc. Nat. Hist., 1875, XVII. p. 509.) In 1878 these limestone rocks (the Portland series of Matthew) are referred to the Taconian, and the gneiss (Laurentian) to the Montalban, by the same writer. (Proc. Bost. Soc. Nat. Hist., 1878, XIX. p. 278 ; Preface to the Second Edition of the Chemical Geological Essays, p. xxii. ; Azoic Rocks, p. 181.)

From the above it seems that Dr. Hunt would not admit as proved the presence of any Laurentian, but would take the limestones belonging according to Matthew to that formation and place them above the Coldbrook group as Montalban and Taconian. Dr. Hunt's statements seem to have no substantial basis of facts ; they are mere lithological speculations. Instead of trying to ascertain whether his theories are correct, he assumes that they are so, and by faults, overturns, etc. endeavors to make the stratigraphy coincide with his theoretical views. The fault is always in the formation, never in the theory. According to Dr. Hunt's own statements, he had, previous to his visit to New Brunswick in 1869 and 1870, but little acquaintance with Huronian rocks. Since that, however, he has referred the felsites of Eastern Massachusetts, Pennsylvania, Missouri, and elsewhere, to the Huronian, because they lithologically resemble the rocks of New Brunswick, referred by him to that age. He ought, therefore, if he really believes that rocks of the same kind can only occur at the same epoch, to now refer all these felsites to the Upper Silurian, Prof. Bailey having shown that to be their true position, as stated on a previous page. We, however, believe that they are rhyolitic lavas and ashes, and hence that they may occur at any age and time. That they are of volcanic origin is admitted by Mr. Selwyn also.

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* Observations on the Geology of Southern New Brunswick, pp. 29, 31, 50.

The reader should not fail to notice that, if credit is due any one for the so-called establishment of the Huronian in New Brunswick, such credit is to be given to Messrs. Matthew and Bailey, and not to Dr. Hunt; also that the last-named gained his chief knowledge of the Huronian rocks from the study of that formation as established by Matthew and Bailey in New Brunswick, — that he was actually their pupil, and not they his, as he would give us to understand.

The various opinions held at different times by the geologists connected with the Survey of New Brunswick with regard to the classification and nomenclature of the older formation will be found presented in the tabular view (Table A.) given herewith.

NOVA SCOTIA.

Prof. Henry Y. Hind in 1870 described two series of gneissoid rocks which he regarded as probably Huronian (Cambrian) and Laurentian. (Quart. Jour. Geol. Soc., XXVI. pp. 468–479.) He gives the following as his reasons for this supposition : —

"1st. The unconformable contact of the Lower Silurian gold-bearing strata with the underlying gneissoid and schistose series.

"2nd. The unconformable contact of this gneissoid and schistose series with the old porphyritic gneiss . . . . before described as Laurentian.

A.

TABLE OF THE PRE-CARBONIFERO FORMATIONS OF NEW BRUNSWICK,

AS ARRANGED BY MESSRS. DAWSON, ILEY, MATTHEW, AND ELLS, 1855–1880.

J. W. DAWSON.		GEORGE F. MATTHEW, 1863.		GEORGE F. MATTHEW, 1865.		BAILEY AND MATTH 1865.	BAILEY AND MATTHEW, 1870–1871.	MATTHEW, 1876–1877.	BAILEY AND MATTHEW, 1877–1878.	BAILEY, 1880.	BAILEY, MATTHEW, AND ELLS, 1878–1879.	
1855.	Silurian.	Devonian, or Devonian and Silurian.	Portland Series.[1] Coldbrook Group.[2] St. John Group.[3] Bloomsbury Group. Little River Group[4] { Dadoxylon Sandstone. Cordaite Shales. Mispeck Group	Laurentian.*	Portland.	Portland.[8]	ort and.	Portland. Coastal.	Portland.	Portland.	Lower } Upper } Portland.	Laurentian.
1861.	Devonian.			Huronian.	Coldbrook { Lower. Upper.[5]	Coldbrook.[9]	wer Coldbrook.[13] omsbury.[14] ugston.[15] astal.[16]	Coldbrook. Bloomsbury.	Lower Coldbrook. Upper Coldbrook. Bloomsbury. Coastal.	Coldbrook. Coastal. Kingston.[20]	Coldbrook [22] Coastal Kingston.[23]	Huronian.
1862.	Devonian. Silurian. (?)			Lower Silurian.	St. John.[6]	St. John.	per Coldbrook. John.	St. John. Lower Kingston.[17]	St. John.	St. John. Kingston.[20]	St. John. Kingston.[23]	Cambrian. Cambro-Silurian.
				Upper Silurian.		Kingston.[10] Mica Schist Group.		Upper Kingston.	Kingston.[18]	Felsites of Eastport and Pembroke.[21]		Silurian.
				Devonian.	Bloomsbury. Little River. Mispeck. } [7]	Bloomsbury.[11] Little River { Dadoxy Sandst Cordaite Shales. Mispeck.	doxylon Sandstone. rdaite Shales speck Conglomerate.	Dadoxylon Sandstone. Cordaite Shales. Mispeck Conglomerate.				Devonian.

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[1] Containing fragments of plants in the upper beds.

[2] Certainly regarded as Devonian.

[3] No proof observed that this group is unconformable either with the over- or under-lying rocks.

[4] Certain rocks afterward separated from this group under the name of Coastal were placed in the above group as Upper Devonian, because they overlie the Dadoxylon Sandstone conformably (or nearly so), and underlie the Carboniferous unconformably, while they partake of the flexures of the Devonian series.

[5] Conformably overlain by the St. John group, but on lithological grounds Huronian.

[6] No unconformability between this group and the Huronian.

[7] These three groups rest unconformably on the Laurentian, Huronian, and Silurian, and were regarded as Middle and Upper Devonian.

[8] Assigned to the Laurentian on lithological grounds. Almost entirely conformable to the overlying unquestionably Upper Devonian groups.

[9] Probably Huronian, both under- and over-lying the St. John group.

[10] Made Upper Silurian (?) on lithological and stratigraphical grounds.

[11] Entirely conformable with the Little River and Mispeck groups; not entirely so with the St. John.

* The names in this column are to be considered as applying to all beyond, except the last two columns.

[12] The entire Devonian series here given was laid down quietly, one group on another, with no marked unconformability or disturbance.

[13] Overlying conformably in places the St John group, and underlying conformably the Devonian.

[14] United with Coldbrook on lithological grounds.

[15] Contains intercalated Upper Silurian strata, but Coastal overlies them.

[16] Overlying Upper Silurian and Lower Devonian strata, but from its lithological characters is placed in the Huronian.

[17] Contains pebbles derived from the St. John group.

[18] Placed here on account of palæontological evidence, although lithologically identical with the Huronian, and apparently dipping beneath that formation.

[20] In part.

[21] Lithologically undistinguishable from the Huronian, and formerly regarded as belonging to that age.

[22] No instance of the superposition of this on the Laurentian observed.

[23] In part.

[These notes represent in a brief form the statements of the geologists above quoted regarding these formations, as given in their publications and in the text preceding.]

> "3rd. The unconformable contact of the gold-bearing series with the Laurentian gneiss, showing the absence of the intermediate gneissoid series, or the Huronian." (*l. c.*, p 474.)

See also Am. Jour. Sci., 1870, (2) XLIX. pp. 347–355; L. pp. 132–134, 417–422.

In order that the conclusions of Prof. Hind may properly be regarded as proved, it is necessary that the age of the gold-bearing strata supposed to be Lower Silurian or Cambrian should be ascertained, and also that the origin of the rocks in question, and their *actual,* not *supposed,* relations to one another be clearly made out, he having apparently determined the order of superposition by the dip of the foliation. Mr. Hind expressly states that his supposed Silurian strata are more altered — bearing andalusite crystals — near the so-called Huronian rocks than at a distance from them. Dr. Dawson regards the so-called gneiss of Prof. Hind as granite, and states that it is intrusive in the gold-bearing strata and Oriskany rocks. Certainly more credit should be given to Dr. Dawson's assertion than to Prof. Hind's negative evidence. (Supplement to Acadian Geology, 1878, pp. 84, 85.)

Mr. Selwyn states regarding this granitic region: —

> "I have examined it in all the above-named districts, and the impression I at present have, is that it is strictly of an indigenous character, and neither an old granitoid gneissic series of Laurentian age, nor an intrusive mass. Dr. Dawson has shown (Acadian Geology, 1868) that in different parts of its course it comes successively into contact with Lower Silurian, Upper Silurian and Devonian rocks, and the manner in which these sedimentary strata are affected at the lines of contact scarcely leaves room to doubt the posterior origin of the granite; but whether as an intrusive mass, or by the metamorphism *in sitû* of the stratified rocks, (in part by a process of molecular re-arrangement of their original component particles,) is perhaps uncertain." (Geol. of Canada, Report of Progress, 1870–71, p. 265.)

Whatever the origin of the granite may have been, evidence of that origin ought to be obtained from an investigation of the relation of that rock to the adjacent ones. Dr. Dawson's statements prove most clearly the eruptive intrusive character of the granite in question, the evidence consisting not only in the induration of the rocks with which the granite comes in contact, but also in its sending tongues and dikes into them. Mr. Selwyn does not furnish any evidence to sustain his views, which seem to be the natural result of an effort to solve problems without a sufficient petrographical examination of the rocks concerned. As we have before repeatedly remarked, such metamorphism *in situ* as is here demanded needs to be proved, before it can be admitted.

Dr. Hunt thinks that the supposed Huronian of Prof. Hind belongs to the White Mountain series; but this conclusion, like most of his geological work, is purely theoretical, based on lithological resemblances. (Am. Jour. Sci., 1870, (2) L. p. 87.)

Dr. Honeyman's papers on the Laurentian age of certain rocks of Nova Scotia, in the Transactions of the Nova Scotia Institute of Natural Science, the Quarterly Journal of the Geological Society, and the American Journal of Science, appear likewise to be valueless, as his conclusions depend chiefly on lithological characters, aided by the distribution of a supposed *Eozoön*. His conclusions are, furthermore, objected to by Dr. Dawson, who states that there is neither stratigraphical, lithological, nor palæontological evidence to sustain them. The rocks in question Dr. Dawson regards as probably Lower Silurian, Cambrian, or Huronian. (Canadian Naturalist, 1879, (2) IX. pp. 1–16.)

According to Mr. Edward Hartley, the Coal Measures near New Campbelltown, Cape Breton, stand vertical, or nearly so, within one hundred feet of syenite and "limestone highly altered serpentinous and crystalline." The dip of the Coal Measures diminishes on receding from the syenite, until they assume a nearly horizontal position (dip 5 or 10 degrees). Since the syenite and limestone resemble the Laurentian, Mr. Selwyn writes: "From the foregoing facts it appears that the Coal Measures in Cape Breton are in direct contact with rocks of Laurentian Age."

The present writers, however, think that nothing of the kind has been proved. It has been simply shown by Mr. Hartley that the Coal Measures are seen highly tilted within fifty or one hundred feet of limestones and syenite of unknown age. (Geol. of Canada, Report of Progress, 1870–71, pp. 4, 5.)

Later, Mr. Charles Robb, in an examination of the same region, states:—

> "The existence of a fault or complication of faults here seems to be proved beyond a doubt, and the occurrence of a band of calcareous and magnesian rocks of varying thickness, between the Lower Carboniferous and Productive Coal-measures on the one hand, and the syenite on the other, is also clearly established."

No eozoönal characters were found in the limestone on microscopic examination. (Report of Progress, 1873–74, p. 174.)

Mr. Robb later gave a much fuller account of the district, with a map of the same. He found a conglomerate containing pebbles of syenite in the Lower Carboniferous rocks, and some of the strata appeared to have been inverted. (Report of Progress, 1874–75, pp. 251–262.)

In commenting upon Mr. Robb's work, Mr. Selwyn remarks : —

> "The examinations recently made by Mr. Robb at Kelly Cove on the Great Bras D'Or Lake show that a similar series of crystalline rocks, — magnesian limestones, serpentine, &c., — occur there between the Carboniferous series and the great mass of syenite, which has been supposed to be of Laurentian age ; but which will, I think, more probably prove to be an *intrusive* mass nearly corresponding in age with the great central granitic axis of Nova Scotia, which is undoubtedly pre-Carboniferous and post-Devonian." (*l. c.*, p. 9.)

This is certainly a striking change in Mr. Selwyn's opinion since 1871. The evidence, however, is strongly in favor of his later views. Mr. Hugh Fletcher, from more extended labors in Cape Breton, rendered it quite evident that in some localities the syenites and felsites are older than some lower Silurian rocks, hence probably Azoic. He relies on lamination solely to prove the sedimentary origin of the rocks in question, and on almost every page shows by his work that he has no knowledge of the characters of eruptive rocks, or of the methods of proving in the field whether the rocks in question are or are not eruptive. His statements concerning their origin are therefore valueless.

The St. George limestone, which he thinks may possibly be Huronian, — although he has classed it as Laurentian, — is said to contain pebbles apparently derived from the syenites and felsites. (Reports of Progress, 1875–76, pp. 371–388 ; 1876–77, pp. 405–428 ; 1877–78, pp. 3–10, F.)

The age of the limestone was not determined any farther than that it was shown to be older than the Carboniferous ; it was simply assumed that it was Azoic. Concerning the Huronian in Nova Scotia, Principal J. W. Dawson remarks : —

> "There is no good evidence that the Cobequid series and its equivalents in Pictou and elsewhere are older than the Lower Silurian. There seems, however, good reason to class as Huronian, or at least as Lower Cambrian, the rocks of the Boisdale Hills in Cape Breton, which Mr. Fletcher finds to underlie the fossiliferous Cambrian of that region, and which are more quartzose and micaceous than the rocks of the Cobequid series. It is not impossible that rocks of this age may also occur in the vicinity of the Cambrian beds found at Miré. We may also conjecturally class as Huronian the chloritic rocks of Yarmouth." (Supplement to Acadian Geology, 1878, p. 88.)

In the same work Dr. Dawson also states regarding the Laurentian : —

> "Dr. Honeyman and Prof. Hind have suggested the Laurentian age of certain rocks as Arisaig, in the Cobequids, and associated with the coast Meta-

morphic series, but I do not regard the evidence of this, either from fossils, mineral character, or superposition, as conclusive, and must refer for it to the memoirs of these gentlemen in the transactions of the Nova Scotia Institute, and the Journal of the Geological Society of London. I must, in like manner, decline to receive as of Laurentian age the felsitic and other rocks of Cape Breton, referred to this system by Mr. Fletcher in the latest Report of the Geological Survey. I would except those of St. Anne's Mountain, the lithological resemblance of which to the Lower Laurentian of Canada is indisputable, and the evidence that they may be of this age has certainly been much strengthened by the recent observations of Mr. Fletcher. Specimens, and the observations of Mr. Brown and Mr. Campbell and others, induce me also to believe that in the little island of St. Paul, and in some parts of Northern Cape Breton, we may have a continuation of the rocks referred by Mr. Murray to the Laurentian in Newfoundland. With these exceptions, I have not seen in Nova Scotia, unless in travelled boulders, any rock that I could believe to be lithologically equivalent to the Laurentian of Canada, nor have I found any stratigraphical evidence of the occurrence of such rocks." (*l. c.*, pp. 89, 90.)

The condition of the question in Nova Scotia can be briefly summed up as follows. In one locality it is probable that some rocks — of, in part at least, doubtful origin — are of Lower or Pre-Silurian age. There is no evidence showing that they should be subdivided into any of the supposed pre-Palæozoic systems, other than lithological, and the finding of some pebbles in a limestone, supposed (not proved) to be the same as the rocks it was desired to place in an inferior position. In fact, beyond the evidence of the pebbles, no proof has been furnished that would justify us in placing any of the rocks of Nova Scotia below the recognized fossiliferous portions.

NEWFOUNDLAND.

The first report of the Geological Survey of Newfoundland made under the general direction of the head of the Canada Survey, Sir William Logan, bears date April 11, 1865. Previous to this, however, Prof. J. B. Jukes made a geological reconnaissance of the island, under governmental authority. This was during the years 1839 and 1840. As Professor Jukes made no attempt to assign names, other than local, to the formation below the Carboniferous, it will not be necessary to take his work into consideration in the present connection.

Mr. A. Murray, in his report to Logan of what was done during the year 1864, recognizes the Laurentian Series as occurring on the northern peninsula of Newfoundland. He gives the following table of the sequence and distribution of the rocks of that region. (*l. c.*, p. 8.)

I. Laurentian Series.
II. Lower Silurian Series. { Potsdam Group. Quebec Group.
III. Upper Silurian Series.
IV. Devonian Series.

After describing the rocks assigned to the Laurentian, which were found to be exclusively of a gneissic character, he adds as follows: —

> "The rocks which have thus been described are considered Laurentian, not merely from the lithological resemblance which they bear to the strata of that series in various parts of Canada, but also from the relation they are seen to have to the Lower Silurian series, which unconformably covers them up in the northern part of the peninsula. . . . . In Canada the Laurentian gneiss is in some parts interstratified with enormous bands of crystalline limestone. . . . . None of these bands have been met with among the gneiss of the northern peninsula." (*l. c.*, pp. 10, 11.)

In the Report upon the Geological Survey of Newfoundland for the year 1868, Mr. Murray introduces into the series of formations of that island an "Intermediate System," which he supposes to be the "equivalent of the Cambrian of England, and the Huronian of Canada." This series he divides into seven distinct groups, admitting, however, that "there are many repetitions of the same strata," and that "a large portion of the country is concealed by superficial deposits of gravel and boulders." The total thickness of the strata thus divided is given at 11,370 feet, the rocks being, with the exception of the upper portion, chiefly slates, and the reason for this manifold division of the series not being apparent in the description of the same. About the middle of the series, in group *c*, "fossil forms, supposed to be of the genus *Oldhamia*," were obtained. In group *d*, also, "some obscure organic remains, resembling the fossils found in *c*," were found. The order of superposition of these rocks was determined by observations made along a section from St. John's to the northern side of Great Bell Isle in Conception Bay. In a note added to the English reprint of the series of Newfoundland geological reports (published by Stanford, in London, in 1881), it is said that the fossil forms "supposed to resemble the *Oldhamii* of Bray Head" were pronounced, on examination by Mr. Billings, the late palæontologist of the Survey, to be undeterminable "He doubted their organic origin altogether." (*l. c.*, p. 144.)

In the Report of the Geological Survey [of Newfoundland] for the year 1872, Mr. Murray notes the discovery of fossil forms in the Huronian rocks of St. John's, which, according to him, "appear to mark out a particular zone or horizon of the formation, which is limited to the subdivision (*d*) of No. 2 Section" of the Report for 1868. These fossils are the *Aspidella* (misprinted *Aspidilla* throughout the report for 1872) *Terranovica* and the *Arenicolites spiralis*, described by Billings in the "Palæozoic Fossils" of the Canada Geological Survey, Vol. II. Part I. pp. 76, 77. The presence of the *Aspidella* was considered by Mr. Murray as being of "marked value as an indicator of the horizon, no form bearing any resemblance to that fossil having ever been recognized in the rocks of the upper series. Nor are they known to exist in any of the strata, by which the slates (*d*) are underlaid." (*l. c.*, p. 17.)

In the Report of Progress [of the Geological Survey of Newfoundland] for the year 1873, the presence of "labradorite and other anorthosites" in the gneissic rocks of certain localities is said to "give rise to the supposition that they belong to the upper or newer Laurentian Series," while angular boulders and fragments of white crystalline limestone are considered to be "suggestive of the proximity of the upper members of the lower series." This is the first intimation that the Laurentian is to be divided into two or more groups, and seems to be merely an endeavor to correlate the older formations of Newfoundland with those of Canada, on a purely mineralogical basis, and on extremely imperfect evidence.

That certain stratified rocks are unconformable with a lower granitic and gneissic formation, called Laurentian, is evident from the facts stated in the Newfoundland reports. That these strata belong to the Primordial or Potsdam division of the Lower Silurian is also made apparent by the character of the fossils which they contain. That these Primordial rocks may be developed to a very great thickness is also rendered probable; although it is not unlikely that a more thorough study of the region would considerably reduce that amount, the region being one difficult of exploration, much disturbed, and largely covered by superficial detritus.

In the Report of Progress [of the Geological Survey of Newfoundland] for the year 1881, the discovery of the *Aspidella* and the *Arenicolites* is again alluded to, as offering "great facilities for the ready recognition of the Huronian when tracing out the structure which, otherwise, would be extremely difficult." The value of the evidence based on the presence of these supposed fossils, as establishing a new system between the Primordial and the Laurentian, will be discussed farther on. At present it need only be remarked that the published sections do not furnish the desired proof of the unconformability of the "Intermediate Series" with the overlying Primordial.

LABRADOR.

In 1863 the gneissoid rocks of Labrador were assigned by the Canadian survey to the Laurentian. In 1865, Prof. A. S. Packard, Jr. gave some account of the geology of the coast of Labrador. It seems at the beginning he mistook for syenite some diabasic rocks, and thought, from finding some pebbles enclosed, that it was formed from a conglomerate. He evidently was not aware that eruptive rocks frequently enclose pebbles that they have picked up. Indeed, it is probable that under the name Syenite Prof. Packard has united very diverse rocks. He assigns some quartzites doubtfully to the Huronian, saying: "Nowhere was I able to see the juncture of this rock with the Laurentian gneiss. . . . . At no point was I enabled to observe whether these quartzites rest unconformably upon the older Laurentian gneiss, though inclined to think so. . . . . The Canadian Geologists likewise state that the strata of the Huronian system have not been observed resting *directly* on tilted Laurentian rocks; it is as yet a matter of hypothesis." Prof. Packard evidently assumed that the foliation of the gneiss or granite was synonymous with stratification.

He pointed out the presence of the labradorite rocks forming the Upper Laurentian of Logan and the Norian of Hunt, but he (Packard) does not seem to have observed its relations to the other rocks. He however found part of it in overflows which he supposed resulted from a refusion of the labradorite rock. His observations point rather to an eruptive than to a sedimentary origin for this "norite." (Memoirs of the Bost. Soc. Nat. Hist., 1868, I. 213–218.

Prof. Packard's Huronian Dr. Hunt regards as Laurentian, but accepts the labradorite rock as Norian. (Amer. Jour. Sci., 1870, (2) XLIX. p. 182.)

Prof. H. Y. Hind later described the Geology of Northeastern Labrador; but, as before, the rocks were referred to the Laurentian on lithological grounds. No evidence was given to show the relations of the so-called Upper Laurentian to the Lower Laurentian, but all rested on theoretical grounds. (Canadian Nat., 1878, (2) VIII. pp. 227–240, 262–278.)

In 1876 Mr. D. F. H. Wilkins illustrated in a paper upon Labrador some of the methods employed in the study of crystalline rocks. The supposed formations were determined by lithological characters, the foliation taken as the lines of stratification, and an apparent dike regarded a representative of the Norian. He says: "The stratification lines are very often so obscure that it is almost impossible to say whether the rocks are metamorphic or eruptive"; and of the Norian at one locality, that it consists of "red-weathering, gray hyperite in a bed two feet thick, overlaid by four feet of whitish gneiss . . . ., seen to repose, at low tide, upon the underlying red gneiss of Lower Laurentian age." (Canadian Nat., 1878, (2) VIII. pp. 87, 88.)

Thus far we have found no evidence except lithological in support of the ages to which the crystalline rocks of Labrador were assigned.

MAINE.

The geological survey of Maine, under Prof. Chas. H. Hitchcock, developed nothing of value as determining the question whether the Azoic system existed in that State. No evidence bearing on this question other than lithological was furnished.

Dr. Hunt in his Geognosy of the Appalachians infers from lithological characters and difference in dip that the "mica schists and gneisses" are of Montalban age, while the "greenish chloritic and chromiferous schists" in the vicinity of Portland are Huronian and older than the gneisses. (Presidential Address, 1871, p. 10.)

Prof. Chas. H. Hitchcock objected to the views of Dr. Hunt, holding that, while the rocks in question were Montalban and Huronian, the Montalban was the older, and the Huronian at this point was deposited upon it. He states that "at the line of junction as observed in Deering, the two groups of rocks possess exactly the same inclination," and declares that, if in their natural position, the gneiss underlies the schist. He acknowledges that the only way these formations have been identified is by lithological characters, remarking that

> "Logan, in 1855, described a system of rocks overlying unconformably the Laurentian gneisses about Lake Huron, which were distinguished by means of

lithological characters. All geologists, therefore, who use the name Huronian, of necessity practically adopt this principle, though perhaps insensibly. We do not claim that a talcose rock can never be found in any other system than the Huronian, nor that gneiss may never be interstratified with the hydromicas. Professor Dana's recent paper shows that gneisses, quartzites and limestones are interstratified in the Lower Silurian of western New England. . . . . In no instance would we claim that mineral character is sufficient to distinguish systems without a study of the relations of the strata. We may sometimes generalize, and believe that rocks of similar mineral character must be of the same age, but such speculations always provide for confirmation by a study of the strata." (Proc. Am. Assoc. Adv. Sc., 1873, XXII. pp. 166, 167.)

We shall see that in New Hampshire Prof. Hitchcock relied entirely on lithological evidence, evidently not following the views here advocated.

In his paper on Granites and Granitic Vein-stones Dr. Hunt referred many of the granites (gneisses) and mica schists of Maine to the Terranovan or White Mountain series, but on lithological grounds. (Am. Jour. Sci. 1871, (3) I. p. 182.)

In two more recent papers by Messrs. Hitchcock and Huntington certain rocks in Northern Maine are regarded as Laurentian and Huronian, if not Montalban; but this decision rests solely on lithological evidence, not the slightest proof being given that the rocks in question may not be much more recent than the Azoic, and of the same instead of different ages. (Proc. Am. Assoc. Adv. Sci., 1873, XXII. pp. 205–214; 1877, XXVI. pp. 277–286.)

Thus far no evidence has been given that proves the pre-Silurian age of any rocks in this State, all the evidence thus far advanced being based exclusively on lithological characters.

NEW HAMPSHIRE.

In this State we have principally to do with the writings of Messrs. Hunt, Huntington, and Hitchcock, these being the geologists who have especially interested themselves in establishing subdivisions in the supposed Azoic rocks of that State. It is in the publications of Prof. C. H. Hitchcock, State Geologist of New Hampshire from 1869, however, that we find the larger part of that which touches the questions here before us.

In stating the results obtained by the Canada Geological Survey, as detailed in the Report of Progress for 1847–48, Dr. T. Sterry Hunt remarked that to the "Chemung and Portage group of New York, with the old red sandstones, ... may perhaps be referred in part the rocks of the White Mountains." (Am. Jour. Sci., 1850, (2) IX. p. 19; Proc. Am. Assoc. Adv. Sci., 1849, II. pp. 333, 334.)

In 1863 he wrote: —

> "It is moreover probable that the rocks of New Hampshire, including the White Mountains, are altered strata of Devonian age." (Geol. of Canada, 1863, p. 598.)

In 1867 the White Mountains were again referred to the Devonian by Dr. Hunt. (Esquisse Géologique du Canada, p. 23; Bull. Soc. Géol. France, 1867, (2) XXIV. p. 687.

Prof. J. P. Lesley, in 1860, stated that he had a

> "growing conviction that the range of the White Mountains would prove to be *synclinal* instead of anticlinal, and therefore of probably Devonian age. . . . . Ascending Mount Osceola . . . . the bridle path mounts over successive outcrop ledges of perfectly horizontal plates of granite, as evidently and regularly bedded as any of the sandstone masses of the Alleghanies, the bed planes not being at all disguised by the cleavage planes. Between these plates of granite lie plates of unchanged dark blue sandstone; a rock which at the cascades . . . . has been mistaken for greenstone trap." (Proc. Acad. Nat. Sci. Phil., 1860, XII. pp. 363, 364. Mining Magazine, 1861, (2) II. pp. 99–101.)

The probable truth in this is, that Prof. Lesley mistook some old basaltic dikes for sandstone, and the concentric lamination of the granite for stratification.

Dr. Hunt, in 1878, stated that Logan suggested that the rocks of the White Mountains were "probably altered Devonian strata" (Azoic Rocks, pp. 86, 87, 182); while, in 1861, he said: —

> "The White Mountains as we suggested in 1849 (this Journal, [2], IX, 19), are probably, in part at least, of Devonian age, and are the representatives of 7000 feet of Devonian sandstone observed by Sir William Logan in Gaspé. Mr. J. P. Lesley has more recently, after an examination of the White Mountains, shown that they possess a synclinal structure, and has adduced many reasons for regarding them as of Devonian age." (Am. Jour. Sci., 1861, (2) XXXI. p. 403.)

In 1870 it would appear that, under the name Terranovan, they were regarded by him in part at least as Potsdam. (Am. Jour. Sci., 1870, (2) L. pp. 83–90.)

In the First Annual Report of the New Hampshire Geological Survey, 1869, Prof. C. H. Hitchcock divided the rocks then examined as follows: —

"Gneissic, Granitic or White Mountain Series.

Staurolite Schists	Quebec Group.
Lower (mostly green) Schists	
Copper Belt	
Clay Slate	
Auriferous Conglomerate	

Upper Schists."

Prof. Hitchcock in that Report states that

"there are two general divisions . . . ., first the granitic and gneissic rocks which appear to be older and consequently to underlie the formations of the second or Quebec group — the true auriferous strata. The name Quebec is that applied by Sir W. E. Logan, of Canada, to rocks . . . . shown to constitute a new group, not present in the New York series, but lying between the Calciferous Sandrock and the Chazy Limestone." (*l. c.*, p. 17.)

No evidence is given to show that the rocks belong to the Quebec group, and that the granite is not eruptive, nor are its relations to the supposed Quebec group stated. All is based upon theoretical grounds.

In the Second Annual Report, 1870, the rocks of New Hampshire are arranged as follows: —

"1. *White Mountain or Gneissic series*, subdivided into

1. Normal Gneiss.
2. Ferruginous Gneiss.
3. Granitic Gneiss.
4. Feldspathic Mica Schist.
5. Andalusite Gneiss.
6. Chiastolite Slates.
7. Granite.
8. Syenite.
9. Porphyritic Granite.
10. Quartzites.
11. Limestones.
12. Soapstones.

"Little doubt remains as to the Eozoic or pre-Silurian age of this entire series."

"2. *Sienite of Exeter and Dover.*

"There appear to be sienitic rocks of probable Laurentian age, equivalent to the Quincy sienitic group of Massachusetts, ... in the towns of Exeter and Dover. They form, apparently, an anticlinal mass, overlaid by the Merrimack slates."

"3. *Porphyritic Granite.*

"Common granite full of large crystals of feldspar. . . . . Some portions of it have evidently been injected, while the arrangement of the feldspathic crystals in parallel lines leads to the suspicion of stratification in other cases."

"4. *Common Granite.*

"The granite of New Hampshire seems to have originated at five different periods. First are the (*a*) indigenous and (*b*) eruptive granites of the White Mountain series ; second, the (*c*) indigenous granites of the Merrimack group, in which none of the eruptive class have yet been seen ; third, the (*d*) indigenous and (*e*) eruptive granites of the Coös and calciferous mica schist groups."

"5. *Merrimack Group.*

"They probably belong to the earliest Silurian series."

"6. *Quebec Group.*

"Lower Silurian, according to Sir William E. Logan."

"7. *Coös Group* of slates, schists, quartzites, etc.

"It appears clearly to overlie the White Mountain *veins* unconformably."

"8. *Calciferous Mica Schist.*

"9. *Clay Slates.*

"8 and 9 seem to be limited outliers in New Hampshire." (*l. c.*, pp. 31–34.)

In the Third Report, for the year 1870, it is stated that

"the White Mountain rocks are believed to belong to two great systems, the Gneissic and the Coos Group. The first are, for convenience, called the White Mountain series. . . . . These rocks appear to underlie the Coos group, and are therefore older. The presumption is that they are entirely Eozoic, though it is not clear whether they are to be considered as the equivalent of the Laurentian of Canada, or more nearly the age of the Cambrian of Great Britain as restricted by the Government Survey. . . . . Its satisfactory reference to the Eozoic series will enable us to clear up the obscurities of New Hampshire geology."

The Coös group was placed as before above the White Mountain series, and, "judging from fossils in Nova Scotia, this group is not far from the St. Johns slates in age." (*l. c.*, pp. 9–11.)

In the next Report, — that for the year 1871, — some changes were made in the general arrangement of the rocks, which were classed as follows : —

"1. Porphyritic Gneiss.

"We suppose this to be the oldest formation among the mountains. Geologists speak of a rock of this character as common in the laurentian in various parts of North America and Europe."

"2. Bethlehem Gneiss.

"It is usually granitic, so much so that it has always been called granite heretofore. . . . . Lying between outcrops of porphyritic gneiss the natural inference is that it is a synclical, and therefore newer, while the strike indicates a very great antiquity judging from the same phenomenon elsewhere. . . . . If the anticlinal structure is persistent, evidence may be afforded that this peculiar gneiss is older than No. 1."

"3. Gneiss.

"4. White Mountain or Andalusite Gneiss.

"It seems to be newer than Nos. 1 and 2, but the relations to the granites and norian are yet to be made out.

"5. Common Granite.

"The joints passing through this rock are both horizontal and vertical. . . . . East of Saco the Andalusite gneiss seems to have been cut by it."

"6. Trachytic Granite.

"Above No. 5, with the same horizontal appearance."

"7. Brecciated Granite.

"The rock is irregular in arrangement as if thrust up from below. As it contains no fragment of the common and trachytic granite, we have concluded it to be more ancient than either of these granites, but newer than the porphyritic gneiss. The two areas are also probably connected beneath the Pemigewasset valley under the common coarse granite, which either flowed in above the breccia or was deposited upon it quietly in some other way."

"8. Norian.

"This includes several areas of labradorite rock, including compact felsites, breccias and syenites."

"9. Clay, Slate and Quartzites.

"10. Coos Group."

Concerning the age of the Norian and some others of the preceeding divisions, Prof. Hitchcock remarks: —

"All will agree that the mineral labradorite belongs to the original laurentian system, and therefore by its discovery in New Hampshire will be satisfied that some of our crystalline rocks belong to the older series of the Eozoic, and not the Paleozoic. Hence the prevalent opinion respecting the age of the New England metamorphic rocks must be changed to conform with the discovery of labradorite in our state. . . . . Our conclusions as to the absolute and relative ages of the New Hampshire formations depend upon the reference of some of them to the Norian system of Hunt." (*l. c.*, pp. 4–10.)

Dr. Geo. W. Hawes regarded the Norite rock as eruptive, saying: —

"At some points the rock possesses all the structure of an eruptive mass, and when in other places this is not found, the evidence furnished by more favorable localities, as well as that furnished by allied rocks in other lands where they have been more thoroughly investigated, must at present be decisive." (Geol. of New Hampshire, III., Part IV. p. 165.)

This rock was accepted by Dr. T. Sterry Hunt as Norian in 1873 (Proc. Bost. Soc. Nat. Hist., 1873, XV. p. 310), but in 1878 he remarked : —

"The labradoritic rocks in the White Mountains, which had by Hitchcock been referred to norite, are now found by him to be eruptive masses." (Azoic Rocks, p. 161.)

In a paper by Prof. Hitchcock (Am. Jour. Sci., 1872, (3) III. pp. 43–47), on the "Norian Rocks in New Hampshire," the following is advanced to show their sedimentary origin : —

"The first rock seen is a gneiss with nodular orthoclase, dipping by compass about 80°, S. 70° W. The strata are indicated by folia of a dark hypersthenic mineral, often forming bunches or nodules. Jointed planes dipping about 25° westerly might be mistaken for strata.* One might be so easily deceived, that it seems as if they must be the planes described at the Cascades and on Mount Osceola by J. P. Lesley. . . . . A few rods higher up the stream . . . . the first ledge of the labradorite rock appears. . . . . It is a perplexing matter to determine the lines of stratification, as the outcrops are divided by two prominent sets of jointed planes, either of which might be called layers of deposition, the rock being essentially homogeneous. One set dip about 20° northerly and are the most numerous. The other dip about 75°, W. 10° S. The latter correspond better in position to the gneissic strata first seen than the former."

In the Report for 1871, published in the summer of 1872, we have the following statements regarding the same rocks : —

"The first rock seen was called gneiss with nodular orthoclase, with its supposed strata dipping by compass 80° S. 70° W. . . . . the presumption arises that these so-called strata may be bands of mica whose planes do not correspond with those of accumulation, but have been superinduced during the metamorphism of the rock. The jointed planes dipping about 25° westerly would be those of stratification, if the rock is stratified. These were pointed out by J. P. Lesley. A few rods up Norway Brook appears the first ledge of the Ossipyte [the labradorite or Norian rock]. . . . . Considered as an isolated case it is difficult to determine the planes of stratification since two prominent sets of jointed planes exist, either of which might be taken for strata. One set dip about 20° northerly, and are the most numerous. The other dip about 75° W. 10° S. As the latter correspond better in position with the supposed strata of nodular gneiss, it was thought they indicated the proper lines of deposition. The former, however, are what appear at the first glance to be the strata, and as by this interpretation the position of the rocks at Waterville will correspond with that in Franconia about the Lafayette range, our former ideas must be modified." (*l. c.*, pp. 15, 16.)

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* Same statement in Atlas of New Hampshire, 1877, p. 11.

Again, in a paper read a few months later, Prof. Hitchcock said: —

"In ascending from 'Beckytown' the first rock met with is 'trachytic granite.' This I called 'gneiss with nodular orthoclase' in my first sketch, with seams or strata dipping (by compass) 80° south, 70° west. . . . . A careful examination of this granitic rock in numerous localities leads to the conclusion that it is a true erupted granite and not a gneiss; though it is possible the present case may be an exception. . . . . The first ledge of *ossipyte* appears a few rods higher up. . . . . The rock seems to be stratified, the planes dipping about twenty degrees northerly. . . . . The importance of this discovery may be best appreciated by remembering that the presence of the lime feldspars affords a strong presumption that these rocks are Eozoic, and not metamorphic Paleozoic formations. It seems to be generally admitted by geologists that these feldspars are confined to the older rocks, except as found in eruptive trappean and volcanic masses." (Proc. Am. Assoc. Adv. Sci., 1872, XXI. pp. 135–151.)

In the second volume of the Final Report on the Geology of New Hampshire, pages 210, 214, 257, 258, 266, the following statement is made regarding the labradorite and its associated rocks: —

"None of the Labrador areas, whether in America or Europe, have yet been carefully studied stratigraphically, so that we have not the means of knowing their thickness. The lines of iron ore and other foreign minerals better agree with the idea of stratification than to suppose the masses are eruptive. In the study of New England rocks, the labradorite aids us greatly, since most geologists are prepared to accept it as indicating formations of Eozoic date; and, if these triclinic feldspar layers rest upon strata formerly thought to be Paleozoic, they render it probable that both the underlying and contiguous masses belong to very ancient systems. . . . .

"A few rods above [Beckytown] is an exposure of the same rocks with those seen at the falls, dipping 80° S. 10° W. The strata are indicated by folia of mica and a little of a dark hypersthenic mineral, often forming nodules. There are jointed planes, also, with a dip westerly of 25°. . . . . Between Norway and Cascade brooks there seems to be an anticlinal axis in the porphyritic gneiss. At first I was satisfied that this rock was gneiss, but did not recognize its true place with the porphyritic group. Subsequently I referred it to the 'trachytic' or Albany granite, but a reëxamination in 1875 shows that it belongs to the oldest of our formations, and is distinctly stratified, traversed by trap dykes and narrow banded veins of quartz. These exposures do not occupy more than two hundred feet of distance. A few rods up Norway brook appears the first ledge of the ossipyte. . . . .

"Considered as an isolated case, it is difficult to determine the planes of stratification since two prominent sets of jointed planes exist, either of which might be taken for strata. One set dip about 20° northerly, and are the most numerous. The other dip about 75° westerly. More definitely, the following are the supposed strata dips seen in ascending; about 20° to N. 26° W., N. 86° W., N. 34° E., and N. 46° W. The joints have these strikes, N. 22° W., N., and S. . . . . The evidence is plain that the Labrador system does not include, besides the triclinic feldspars, the porphyries and all the Pemigewasset granites. Hence the statements respecting the nature of the events transpiring in the Labrador period, — given in the chapter upon the physical history of the strata, — pertain to a later epoch. . . . . We are therefore led to believe that the labradorites alone represent the Labrador system, and, as thus limited, it has been described. . . . . There are seven small areas of it, cut by a sort of 'sienite' containing triclinic feldspars, and therefore supposed to close the period. . . . . The reality of the system is not affected by the removal from it of these various porphyries and granites. Their elimination makes the correspondence perfect between the New Hampshire and Canadian areas, thus establishing more firmly the existence of the series. Some difference of opinion may exist among geologists as to the relations between the Montalban and Labrador systems. . . . . The labradorite rocks, with a very moderate dip, rest unconformably upon the greatly upturned edges of the Montalban schists, as if there had been large upheavals at the close of the Montalban period, and comparatively little disturbance since. . . . . The facts as interpreted are of great consequence, since they fix the geological horizon of the whole Atlantic system, while considerations of a stratigraphical character confirm this impression. . . . . The discovery of the Labrador system, overlying the most abundant and characteristic White Mountain strata, makes it clear that the latter are older than the former, which are confessedly Eozoic."

In the Final Report on the Geology of New Hamphire, Vol. II. p. 667, Prof. Hitchcock remarks as follows: —

"The Labrador system, if present in New Hampshire, is in very limited amount. Recent investigations make it difficult to say that the labradorite rocks are not of eruptive character. They have the composition of dolerite; and certain exposures of them upon Mt. Washington are surely injected dykes. Hence great doubt arises whether the larger area of Waterville really represents the Labrador system of Canada. At all events its age is great, for these dykes cut through Montalban strata. This dolerite may be regarded as one of the oldest eruptive rocks in the state, coming to the surface in what was the Labrador age of the world."

Resuming the Report for 1871, we find the relative geological position of the formations to be stated as follows: —

"The sections given of the common granite, trachytic granite and the norian series (or at least certain felsites,) seem to determine their relative positions, the last being at the top. The brecciated granites of Franconia seem to be older than any of these, and to underlie them. . . . . If these points are assumed, the porphyritic gneiss can be shown to be at the bottom of the series, for it lies outside of the lowest of them. . . . . We cannot as yet locate the andalusite gneiss, save that it is newer than the porphyritic bands as shown at Moosilauk. . . . . The Coos group of Littleton and Lisbon passes around the west end of the Bethlehem gneiss, showing that the latter existed before either the deposition or elevation of the former. This indicates that the whole of the White Mountain rocks are more ancient than the Coos and Quebec groups of the Connecticut valley." (*l. c.*, pp. 25–27.)

In the Report for 1872, the Quebec group of the earlier reports is assigned to the Huronian. The Porphyritic group is described as consisting

"mainly of gneiss full of large crystals of orthoclase feldspar, associated with ferruginous and other bands. It is regarded as the oldest of all the formations in the State for these reasons :

"1. The principal range is flanked on both sides by similar varieties of gneiss, and later series of rocks in the same order. The newer groups being outermost, the anticlinal rather than the synclinal structure is suggested, and hence the greater antiquity of the central range.

"2. This rock is apparently covered by the other members of the gneiss series in the northern part of the State.

"3. The lithological chamber [? character] corresponds with that of known Laurentian strata in Canada, North Carolina, and elsewhere." (*l. c.*, p. 11.)

Of the "Concord granite" Prof. Hitchcock says : —

"This rock is not a proper granite. There is an arrangement of the particles of mica along parallel planes, which allows the rock to split readily. These we regard as strata." (*l. c.*, p. 12.)

In 1872 Professor Hitchcock presented the following classification of the rocks of New Hampshire : —

"I. EOZOIC.

"1. *Laurentian*, including (*a*) porphyritic gneiss ; (*b*) White Mountain series, r andalusite gneiss ; (*c*) Bethlehem, or talcose gneiss ; (*d*) gneiss of Lake Winnipiseogee Basin ; (*e*) gneiss on both flanks of the porphyritic variety in the south part of the State, subdivided by bands of quartzite, — this carries the Concord and Fitzwilliam granites, and is probably the beryl-bearing series also ; (*f*) range of gneiss between Whitefield and Milan, considerably hornblendic.

"2. *Norian*, including (*a*) common granite ; (*b*) trachytic granite ; (*c*) four bands of felsite, both labradorite and orthoclase.

"3. *Exeter syenites*, including those cutting the Norian at Waterville, Mount Monadnock, opposite Colebrook, Redhill, &c.

"4. *Huronian.* The talcose schist series along Connecticut River, and in the north part of Coös County.

"5. *Older Cambrian?* Includes Coös and Merrimack groups, and probably the 'Calciferous Mica Schist' of Vermont Survey.

"II. PALEOZIC.

"Helderberg limestones.

"Clay slates."

In discussing these formations it is later stated as follows: —

"If these granites behave like a stratified formation, of course the question is at once raised whether they should not be regarded as true strata. The answer cannot be given from position merely, since it is not uncommon to find sheets of trap or lava holding a perfectly analogous position. We have preferred to think of the White Mountain country at the end of the Laurentian period as an immense basin, upon which there was an overflow of common granite. Being liquid, it spread itself out like water, assuming a horizontal surface. After a while there was an eruption of trachytic granite, which spread itself in the same way. Subsequently the felsites were formed above them conformably. It would be natural to regard these granites, and felsites as belonging to one period, the Norian. The limits of this system have not been fixed; and it seems as if in New Hampshire it should commence in the common granite, and end with the red orthoclase felsite. . . . .

"If the felsite series is of the age of the Upper Laurentian or Labrador of Logan, then by the law of superposition the strata underneath the common granite are Lower Laurentian. Observation showed us, at this phase in the development of the White Mountain structure, two gneisses and a breccia underneath the granite sheet. The most important is the '*Porphyritic gneiss*,' or granite sometimes. This is a gneiss having large crystals, usually one and a half inches long, of orthoclase, arranged in layers in the mass, with the longer axes parallel to one another. These we conceive to be the strata. . . . .

"The description of the Laurentian rocks in Canada and Europe make mention of large quantities of porphyritic gneiss; hence we feel warranted in referring these lower schists to the Laurentian system. We have yet found nothing older in the state. . . . .

"Our explorations have brought to light the existence of ten distinct periods, whose records can be traced upon the scarred sides of these highest mountains of New England. . . . .

"If our limited opportunities have led to such unexpected results, what may we not look for when the geological structure of the entire metamorphic area of New England has been carefully studied!" (Proc. Am. Assoc. Adv. Sci., 1872, XXI. pp. 134–151.)

In 1873 Prof. Hitchcock remarks that the evidence of the inferior position of the White Mountain or andalusite gneiss

"to the Labrador group is very decided. . . . . In the valley of Dry or Mt.

Washington River, ... there is a limited synclinal of ossipyte resting upon the upturned edges of the andalusite gneiss." (Proc. Bost. Soc. Nat. Hist., 1873, XV. pp. 304–310.)

In the second volume of the New Hampshire Geology, Prof. Hitchcock writes as follows : —

"Another important doctrine relates to the identification of formations in our field of labor by means of mineral characters. . . . . The style of similarity made use of for identification is better shown in the porphyritic gneisses. There are over thirty areas of porphyritic gneiss, in which the feldspar crystals are very conspicuous for their size, the rock being the *Augen gneiss* of Europe I assume that all the areas of this rock are identical in age, and, in speculating upon the relative positions of the intervening groups, rely upon the correctness of this starting point. . . . . The fact of minor differences would seem to confirm our assumption of their identity in age, just as the paleontologist finds, from the presence of the same fossils, proof of contemporaneity in rocks with dissimilar mineral character. From these facts [the supposed relations of the rocks] it is inferred that the porphyritic gneiss is older than either the Lake or the Montalban gneisses, the last being the newest. . . . . It may as well be said now as at any time, that nothing older than the porphyritic gneiss has yet been discovered. This formation constituted the first dry land in the state." (*l. c.*, pp. 659, 660, 663, 664.)

The equivalency of the New Hampshire formations with others is in part stated as follows : —

"The first two of our groups may be referred to the oldest of these, the Laurentian, without great hesitation. . . . . A porphyritic or *augen* gneiss is eminently characteristic of the fundamental rocks in every part of the world, and hence ours may readily be called Laurentian. . . . . Those who are familiar with the crystallines, as Prof. Dana and Dr. Sterry Hunt, after examining some parts of the Bethlehem group in New Hampshire, say that there is a close resemblance between them and the Laurentian. . . . . I have grouped these rocks, the porphyritic and Bethlehem gneiss, as Laurentian.

"The next division, the Lake gneiss, cannot be so readily assigned. Its affinities are strongly with the Laurentian, but it is not pyroxenic nor porphyritic, nor does it abound in any triclinic feldspar. . . . . In Massachusetts this group carries the *Eozoön*, but that fossil is not confined to the Laurentian. . . . . The Montalban series are certainly not characteristic of the Laurentian. . . . . Dr. Hunt is satisfied that they *overlie* the Huronian or greenstones. Our own observations lead to the view that the typical Montalban rocks *underlie* the same, as recently stated, though the precise relationship is not beyond controversy." (*l. c.*, pp. 668, 669.)

The other formations are in like theoretical manner referred to their supposed places, with the exception of the Helderberg series.

Again, it is said regarding the arrangement of the feldspar in the "Porphyritic gneiss or granite," that

> "sometimes the crystals are placed in the rock with their longer axes parallel to each other, and this plane is coincident with that of the strata. On the contrary there is often no arrangement to correspond with the stratification. . . . . It is obvious that one of these rocks must be granite and the other gneiss. In our explorations no distinction has been made between them. The assumption has been that the agencies producing the granite operated with greater intensity, so as to induce a party condition in the mass, and obliterate the stratification without destroying the porphyritic aspect of the rock. If the difference in condition involves radical distinctions in the mode of origin or in the time of the fusion, then there are two formations to be considered instead of one. But in that event the second rock was derived from the first, so that the assignment of both to one group at present will not lead to error in respect to the geographical areas occupied by the porphyritic rock. . . . . Being regarded as granite, no pains were taken to observe lines of stratification in it which doubtless exist. . . . . The determination of the dip of this rock near the wing road station has been a difficult matter. There are jointed planes, with scarcely any inclination that might be taken for strata. At the suggestion of Dr. T. Sterry Hunt, a crystalline arrangement of materials dipping 75° S. 40° E. was decided upon to represent the strata." (Geology of New Hampshire, II. pp. 98, 99, 102, 274.)

In the same work, pages 472, 513, 514, Mr. J. H. Huntington says of the porphyritic gneiss : —

> "The fact that rounded fragments of a dark gneiss are found in the porphyritic shows that the porphyritic rock in Fitzwilliam is either intrusive, or that in the process of metamorphism these fragments were not obliterated, and that the dark gneiss — which is very limited, but resembles some varieties of the Bethlehem gneiss — is the older rock."

He further points to the fact that the Concord granite at Fitzwilliam was intrusive. (*l. c.*, p. 513.)

Mr. Huntington also informs us that the "Concord" granite (Montalban gneiss of Hunt) at Granby, Vermont, is distinctly eruptive, being seen in contact with a mica schist, sending tongues into the schist and including fragments of it.

After reading the speculations and conclusions given above, it is somewhat interesting to peruse the following from Prof. Hitchcock's pen : —

> "It has been our constant aim to so divorce the facts and theories from each other in the descriptions, that those who hold different general views from our own will not find the observations unwarrantably obscured by individual speculations. . . . . If our interpretation fails in any particular it will be in the

neglect to invoke all the inversions and faults that are required for truthful elucidation." (Geology of New Hampshire, II., pp. 658, 659. See also Am. Jour. Sci., 1877, (3) XIV., pp. 316–321; 1878, XVI., pp. 399–401.)

Since it was evidently the case on the New Hampshire Survey that lithological characters were considered to be all-important in the determination of the age of the crystalline rocks, it seemed desirable to find out what amount of skill had been shown in ascertaining what the character and true names of these rocks really were. A few results of a partial examination, by Dr. Wadsworth, of one of the collections of the New Hampshire Survey, obtained from the State Geologist, may therefore be here introduced for the purpose of throwing light on this question.

As an example of the value of the lithological determinations of this Survey, the typical Exeter syenite may be first taken. The specimen is No. 71 of Hawes's Catalogue, and No. 200 of the "Preliminary Catalogue." This rock is said by Prof. Hitchcock to be lithologically the same as the country-rock of the Merrimac mine at Newburyport,* and the hornblendic granite of Gloucester and Quincy, Mass. All these are regarded as being probably of Laurentian age, and it is recomended that search be made in the Exeter rock for mineral veins, on account of its resemblance to that in which the Merrimac mine is found. The theoretical idea at the base of this piece of advice seems to be, that, even in eruptive rocks, identity of lithological character indicates identity of age, and the probable occurrence of similar metalliferous deposits. (See Geology of New Hampshire, I., p. 27; II., pp. 22, 630; III., Part V. p. 34.) It has by no means been established, as the result of observation, that rocks of the same geological age and mineralogical composition contain the same useful ores; but in the present case it is not necessary to go so far as this, since it can easily be shown that the rocks to which reference is here made have no lithological resemblance to each other.

The Quincy and Gloucester (Cape Ann) hornblendic granites (syenites) were described by Dr. Wadsworth in 1878 (Proc. Bost. Soc. Nat. Hist., XIX., pp. 309–316). They consist of grayish, granitoid, coarsely crystalline aggregates of feldspar, quartz, and hornblende. In some places this granite has a reddish color. This rock was found, on careful examination, at Rockport, to pass, in the same continuous mass, into a micaceous granite, the only difference between the two being that lepidomelane replaced the hornblende. The feldspar proved to be mainly orthoclase. The country-rock of the Merrimac mine, on the other hand, is a dark-greenish micaceous and hornblendic schist and gneiss, not having lithologically a single character of the Quincy or Cape Ann granites or syenites.

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* The real location of the Merrimac mine is, however, in Newbury, not Newburyport.

The specimen of "Exeter syenite" obtained from Prof. Hitchcock, and now in the lithological collection at the Museum of Comparative Zoölogy, is unlike either of the preceding rocks. Macroscopically it appears to be composed of feldspar and biotite, a large proportion of the former appearing as well-striated plagioclase. From its resemblance to rocks of similar character occurring in Maine, it appeared likely that it belonged rather to the basalts than to the granites; in other words, that it was a basic instead of an acidic rock. Microscopic examination of a thin section showed, in fact, that the rock is composed of plagioclase, a little orthoclase, augite, biotite, magnetite, apatite, and some quartz. The augite is seen in places to have suffered alteration and to be partly changed to biotite, a common occurrence, rendering it probable that all the biotite is of secondary origin. The quartz is in small amounts, and occupies the angular interspaces usually filled by the base in such rocks when unaltered; it is therefore probable that it has either replaced the glass in the process of alteration, or was itself residual silica after the other minerals had crystallized out. The plagioclase proves, as determined by the method of Descloizeaux, to be labradorite. This rock, therefore, is a gabbro, or a coarsely crystallized diabase, and belongs rather to the so-called Norian rocks (basaltic) than to the granites. (See M. E. Wadsworth in Proc. Bost. Soc. Nat. Hist., 1877, XIX., pp. 217–238; Bull. Mus. Comp. Zoöl., 1879, V., pp. 275–287.)

We have here, therefore, three rocks, almost as different from each other as it is possible for rocks to be, placed together as alike; and, on this presumed analogy, practical advice in regard to exploration for mining purposes is based.

Another instance which may be cited as illustrative of the value of the lithological determinations of the New Hampshire Survey is that of No. 71 of the Preliminary Catalogue, there called hornblendite, and No. 221 of Hawes's Catalogue, where it is designated as hornblende schist. The locality is Piermont, N. H., and the region where this rock occurs is described as being made up of alternating bands of whetstone slate (mica schist) and hornblende (hornblende schist). Prof. Hitchcock states that

"there are five bands of hornblende schist and five of whetstone slate. . . . . I am inclined to carry out the suggestion of a previous page, to the effect that much of this hornblende should be regarded as Huronian. In agreement with this notion, it would form hummocks underlying the mica schists, probably

ANNUAL REPORTS : 1869–1872.

1st Annual Report, 1869.

Gneissic, Granitic, or White Mountain Series.

- Quebec Group.
  - Staurolite Schists.
  - Lower (mostly green) Schists
  - Copper Belt.
  - Clay Slate.
  - Auriferous Conglomerate.

Upper Schists.

2d Annual Report, 1870.

- Eozoic.
  - White Mountain or Gneissic Series.
    - Normal Gneiss.
    - Ferruginous Gneiss
    - Granitic Gneiss.
    - Feldspathic Mica Schist.
    - Andalusite Gneiss.
    - Chiastolite Slates.
    - Granite.
    - Syenite.
    - Porphyritic Granite.
    - Quartzite.
    - Limestones.
    - Soapstones.

Laurentian (?) Exeter Syenites.
Porphyritic Granite.
Common Granite.

- Lower Silurian
  - Merrimac Group.
  - Quebec Group.

Coös Group.
Calciferous Mica Schist.
Clay Slates.

3d Annual Report, 1871.

- Laurentian (?)
  - Porphyritic Gneiss
  - Bethlehem Gneiss.
  - Gneiss.
  - White Mountain or Andalusite Gneiss.
  - Common Granite.
  - Trachytic Granite.
  - Brecciated Granite.
  - Norian.

Clay Slate and Quartzites.
Coös Group.

4th Annual Report, 1872.

DIVISION 1.

- Huronian.
  - Hydro-mica and Talcose Schists,
  - Conglomerates, and Quartzites.
- Cambrian.
  - Auriferous Clay Slates.
  - Coös Group.
    - Quartzites, Staurolite Schists,
    - Mica and Argillaceous Schists,
    - Calciferous Mica Schist,
    - Decomposing Slates, Dikes.

Helderberg.

DIVISION 2.

- Laurentian.
  - Porphyritic Gneiss and Granite.
  - Bethlehem and Berlin Gneiss.
  - White Mountain or Andalusite Gneiss.
  - Franconia Breccia.
- Norian.
  - Pemigewasset Basin.
    - Common Granite.
    - Spotted Granite.
    - Four Series of Compact Feldspar.
    - Green Granite and Syenite.

DIVISION 3.

- Laurentian
  - Porphyritic Gneiss and Granite.

Granitic Gneiss.

- White Mountain Series.
  - Andalusite Gneiss, Ordinary and Imperfect Gneiss, the Concord and Fitzwilliam Granite, Soapstone and Limestone.

Quartzite.
Mica Schist.
Andalusite Slates of the Coös Group.

PROC. AM. ASSOC. ADV. SCI., 1872, XXI. 134, 135, 150.

- I. Eozoic.
  - 1. Laurentian.
    - *a.* Porphyritic Gneiss.
    - *b.* White Mountain Series, or Andalusite Gneiss.
    - *c.* Bethlehem, or Talcose Gneiss.
    - *d.* Gneiss of Lake Winnipiseogee Basin.
    - *e.* Gneiss on both flanks of the Porphyritic variety in the south part of the State, carrying the Concord and Fitzwilliam Granite, and is probably the Beryl-bearing Series.
    - *f.* Range of Gneiss between Whitefield and Milan, considerably hornblendic.
  - 2. Norian.
    - *a.* Common Granite.
    - *b.* Trachytic Granite.
    - *c.* Ossipyte.
    - *d.* Compact Labradorite Felsite.
    - *e.* Dark compact Orthoclase Felsite.
    - *f.* Red compact and Crystalline Orthoclase Felsite.
  - 3. Exeter Syenites.
  - 4. Huronian
    - The Talcose Schist Series.
  - 5. Older Cambrian.
    - Coös Group.
    - Merrimac Group, and probably Calciferous Mica Schist of the Vermont Survey.
- II. Paleozoic.
  - Helderberg Limestone.
  - Clay Slates.

BOST. SOC. NAT. HIS., 1873, XV. 304–309.

- I.
  - A. Porphyritic Gneiss.
  - B. Bethlehem Gneiss.
  - C. White Mountain or Andalusite Gneiss
- II
  - A. Common Granite of the White Mountains
  - B. Spotted Granite.
  - Ossipyte
  - D Dark compact Labradorite.
  - E. Dark compact Orthoclase.
  - F. Red compact Orthoclase.
  - Reddish compact Orthoclase
  - H. Syenites of Exeter and Tripyramid.
- III.
  - Talcose and Auriferous Conglomerates.
  - reen Schists.
  - Whitish Schists
  - eldspar and Talc.
- IV.
  - A. Mica Schists of Rockingham County.
  - B. Merrimac Group.
  - C. Coös Group.
  - D. Clay Slates.
  - E. Green Granite.
  - F. Mt. Mote Conglomerates
- V.
  - Helderberg Limestone.
  - Clay Slates.

AM. ASSOC. ADV. SCI., 1873, XXII. 120-131.

- Eozoic.
  - *Winnipiseogee Lake.*
    - Porphyritic Gneiss or Granite.
    - Winnipiseogee Lake Gneiss Formation.
    - White Mountain Series.
  - Eruptive Granites of the Ossipee Mountains.
  - Felsites or Compact Feldspars.

ptive Syenite.
a Schist.

GEOLOGY OF NEW HAMPSHIRE, 1874, I. 506–539.

- Eozoic.
  - Laurentian.
    - Porphyritic Gneiss.
  - Atlantic.
    - Bethlehem.
    - Lake Gneiss.
    - Montalban.
    - Franconia Breccia Group.
  - Labrador.
    - Conway Granite.
    - Albany Granite.
    - Chocorua Granite.
    - Fine Sedimentary Deposits.
    - Eruptive Syenite.
  - Huronian.
    - Copper and Iron Beds.
    - Dolomite, Soapstone, and Serpentine with Siliceous Schist.
    - Conglomerate.
- Mica Schist Period.
  - Rockingham Mica Schist.
  - Merrimac Group.
  - Cambrian Auriferous Clay Slates.
  - Coös Group.

Helderberg Period.

WALLING'S ATLAS OF NEW HAMPSHIRE, 1877.

- Eozoic.
  - Laurentian.
    - Porphyritic Gneiss.
  - Atlantic
    - Bethlehem Group.
    - Lake Winnipiseogee Gneiss.
    - Montalban or White Mountain Series
    - Franconia Breccia.
  - Labrador or Pemigewasset.
    - Conway Granite.
    - Albany Granite
    - Chocorua Granite.
    - Ossipyte.
    - Compact Feldspar.
    - Exeter Syenites.
  - Huronian.
    - Lisbon Gronp.
    - Lyman Group.
    - Auriferous Conglomerate.
- Paleozoic.
  - Cambrian.
    - Rockingham Schists
    - Calciferous Mica Schists.
    - Coös Group.
    - Clay Slates.
    - Mt Mote Conglomerate.
  - Silurian.
    - Helderberg Limestones.
    - Slates, Conglomerates, &c.

GEOLOGY OF NEW HAMPSHIRE, 1877, II. 674, 675.

I. *Stratified Groups.*

- Eozoic
  - Laurentian.
    - Porphyritic Gneiss.
    - Bethlehem Ordinary Gneiss.
    - Bethlehem Fine-Grained Gneiss.
    - Lake Winnipiseogee Gneiss.
  - Montalban.
    - Gneiss and Feldspathic Mica Schists.
    - Concord Granite.
    - Ferruginous Schists.
    - Fibrolite Schists.
    - Franconia Breccia.
  - Labrador.
  - Lower Huronian.
  - Upper Huronian.
    - Hornblende Schist.
    - Swift Water Series.
    - Lisbon Group.
    - Lyman Group.
    - Auriferous Conglomerate.
- Paleozoic (?)
  - Ferruginous Slates.
  - Merrimac Group.
  - Rockingham Mica Schist.
  - Kearsarge Andalusite Group.
- Paleozoic.
  - Cambrian Slates.
  - Coös Group
    - Quartzite.
    - Mica Schist.
    - Staurolite Slate.
  - Calciferous Mica Schist.
  - Lower Helderberg.

II. *Eruptive Masses.*

- Granitic.
  - Conway Granite.
  - Albany Granite.
  - Chocorua Series.
  - Granite cutting Coös Group.
  - Granite not otherwise assigned.
  - Syenite of Mt. Gunstock, etc.
  - Exeter Syenite and Diorite.
- Feldspathic.
  - Labradorite Diorite.
  - Porphyry.
  - Pequawket Breccia.
  - Trachyte.
- Augitic.
  - Diorite.
  - Diabase.

uncomformably. . . . . This theory will explain the occurrence of the whetstone rock in limited outlying patches. . . . . Were it interstratified with the hornblende, it should descend into the earth at the same angle to indefinite depths." (Geol. of New Hampshire, II., p. 379.)

On examination, however, of this so-called hornblende schist, both in the hand specimen and microscopic slide, we find it to be a well-marked diabase, a rock that so far has always, when carefully studied by competent observers, been considered to be eruptive.

No. 121, called "granite from bed" in the Preliminary Catalogue, ("feldspar from bed," Hawes's Catalogue) is the same as the sandstone No. 117 (Prelim. Cat.), both being masses of feldspar with a little quartz. No. 86 of the Preliminary Catalogue, called "serpentine, very impure," from Norwich, Vt., is regarded as Huronian. (Geol. of New Hampshire, II., pp. 360, 361.) This rock is a mixture of quartz and hornblende, with considerable epidote, but we cannot find the slightest sign of serpentine about it, either macroscopically or microscopically.

We might go much further in illustrating the character of the lithological determinations of the New Hampshire Survey, and the probable value of these as forming a basis for a geological classification, but we forbear.

The criticisms here made depend of course on the authenticity of the specimens used. On this point we quote Prof. Hitchcock: —

> "Pains have been taken to have all the specimens exactly alike, so that those who obtain duplicate collections, by purchase or otherwise, may be sure that Mr. Hawes's accurate descriptions in the chapter on Lithology are applicable to their set." (Geol. New Hampshire, Part IV. p. 261.)

Dr. Hawes, however, appears to have had his doubts with regard to the uniform character of the various collections prepared by the New Hampshire Survey, for he expressly states that it is only for the collections preserved in the Peabody Museum at Yale College that he is to be held responsible (*l. c.*, p. 255).*

Further remarks on the methods of work of the New Hampshire Survey, and the character of the classification established on a purely lithological basis, will be found in the second part of this memoir. At present it will be sufficient to present in a tabular form (Table B.) the different results arrived at from year to year, as displayed in the reports of the State Geologist, published while the work was going on. The scheme here presented is as complete as it has been found possible to make it. So numerous are the contradictions in the published statements made from year to year, that only an intimate personal acquaintance with the geology of New Hampshire would make it possible to prepare a connected scheme of the subdivisions of the geological formations of that State, as from time to time set forth in Professor Hitchcock's reports.

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* It is a fact, as shown by actual examination, that, in various collections obtained from Prof. Hitchcock by different parties, specimens bearing the same number, and purporting to be from the same locality, are — in some cases, at least — quite different from each other.

EASTERN MASSACHUSETTS.

The first paper of which the writers are aware, relating to the lithology of the vicinity of Boston, is that of Mr. S. Godon, entitled, "Mineralogical Observations, made in the Environs of Boston, in the Years 1807 and 1808." (Mem. Am. Acad., 1809, (1) III., pp. 127–154, with a Table; Ann. Mus. Hist. Nat., 1810, XV., pp. 455–472.) From this paper it appears that Mr. Godon united under the name *amphiboloid* all the rocks in this region which he supposed to be composed of amphibole and feldspar, when the former mineral predominated. When the latter was more abundant than the hornblende, the rock was called *felsparoid.* It seems from his descriptions that he included under the term amphiboloid part of the granitic and all of the basaltic rocks (diabase, diorite, and melaphyr) except the amygdaloid and possibly some diabase.

The amphiboloid was divided into the following series: Common, Granitic, Trappine, Porphyritic, Epidotic, Quartzose, Micaceous, and Talcous Amphiboloid. The presence of epidote in small veins both in the amphiboloid and felsparoid was noticed and described.

The felsparoid included the hornblendic granite both north and south of Boston, and probably some of the coarser diabases. The felsparoid was said to be often micaceous, and in general to present no distinct stratification. Mr. Godon also remarks, that "the transition of felsparoid to petrosilex and porphyritic petrosilex is frequently observed in the compass of the present observations." He cites, as localities where the transition can be observed, Milton, Blue Hills, and Malden.

The felsparoid was divided as follows: Common, Quartzose, Epidotic, and Granitic Felsparoid.

The felsite he classes under the head of Petrosilex, but thinks that, instead of petrosilex being a simple mineral, as it was then generally regarded, possibly it might be compound in its nature.

He makes the following divisions of the petrosilex: —

" Simple Petrosilex	Flinty Petrosilex.
	Sonorous "
	Jasper "
	Novacular "

" Porphyritic Petrosilex."

The name *simple petrosilex* seems to have been confined to the more apparently homogeneous felsites, while the term *porphyritic petrosilex* was given to those rocks supposed to have a base of simple petrosilex, or of felsparoid which held enclosed porphyritic crystals. The simple petrosilex was thought to pass into wacke and felsparoid.

The common argillite of the country was denominated *argilloid*, and it was supposed to pass into petrosilex. He separated it into the following divisions: Common and Novacular Argilloid. An imperfect chemical analysis was made of some of the argilloid that resembled the *sonorous petrosilex*.

The conglomerate of the district was called *wacke*. Mr. Godon says of it: —

> " How much attention soever I have paid to the examination of this rock *in situ*, I have never observed in it any distinct stratification. It commonly unites with the rocks previously described, and with amygdaloid, often by an insensible transition. I possess specimens, which, on pieces of four inches square each, present its different passages to felsparoid, amphiboloid, simple and porphyritic petrosilex, argilloid, &c."

His explanation of its origin is interesting, not only as illustrating some of the views of that time, but also from its general resemblance to the conclusions and statements in some more recent articles on the geology of Eastern Massachusetts.

> " If permitted to venture an opinion on the mode of its formation, we may suppose, that, as we find in it specimens of almost all the rocks, which predominate in the country, it originated from a motion, which disturbed and divided the vast deposits of felspathic, porphyritic, petrosiliceous, &c. rocks, while they were passing from the state of fluidity to that of solidity. This motion ought to be supposed as having taken place before the complete solidification of these rocks; since the compactness of the wacke indicates that its

elements were in a state of softness, which permitted the union of these heterogeneous bodies to form a solid mass. Moreover this aggregation cannot be supposed to have been formed after the last cast of the primordial deposit, because the rents, which took place in its mass, have been filled by veins or rather strata of amphiboloid and felsparoid . . . . which demonstrates, that these minerals were still depositing themselves, at a period later than the formation of the wacke."

The amygdaloidal basalt (melaphyr) was called amygdaloid, and regarded as made up of nodules cemented by an apparently homogeneous reddish-brown or greenish substance. It is said that

"sometimes it occurs with a schistous texture, and even emits an argillaceous smell, when breathed on. This rock is analogous to the toadstone of the English."

In Godon's work is seen the same theoretical belief in the passage of one rock into another which has since his time played so important a factor in the geological papers in this region, all resting, however, on theory and imperfect observation.

Next in order followed Mr. William Maclure's paper, entitled "Observations on the Geology of the United States, explanatory of a Geological Map," (Trans. Am. Phil. Soc., 1809, VI., pp. 411–428,) which was followed by an enlarged paper on the same subject in 1817. (Ibid., 1818, (2) I., pp. 1–91.) The latter paper was also published as an independent work in 1817. Maclure, following Werner, arranged all rocks in four classes: Primitive, Transition, Floetz or Secondary, and Alluvial Rocks.

Dr. Hunt in his History of the Azoic Rocks (Second Geological Survey of Pennsylvania, 1878, E., Part I. pp. 23, 24) fell into the error of making Maclure's classes of rocks five in number. This was done by Dr. Hunt's placing the "Old Red Sandstone" as a distinct class, although Mr. Maclure regarded it as belonging to the Floetz or Secondary class, being one of the twelve formations into which that class was divided. Dr. Hunt's mistake probably arose from the fact that the "Old Red Sandstone" (Mesozoic) of Maclure was colored distinctively on the map, which was the case with all the *classes,* but not with the *other formations.* This rock was furthermore placed at the base of the Secondary, and regarded as making a passage from the Transition to the Secondary classes.

The rocks in the vicinity of Boston were placed by Maclure in the Primitive and Transition classes. The Transition corresponded generally with the conglomerate in this region, and it was directly connected with the Rhode Island Coal Basin, then regarded as Transition.

Prof. Parker Cleaveland's "Elementary Treatise on Mineralogy and Geology" followed Maclure and Godon in the first edition (1816), with the addition of the Messrs. Dana's observations in the second edition (1822), and therefore no reference need be made to Cleaveland's views.

In 1818 was published the "Outlines of the Mineralogy and Geology of Boston and its Vicinity, with a Geological Map," (Mem. Am. Acad., 1818, (1) IV., pp. 129–223,) by the brothers J. F. and S. L. Dana. This was, and is, a very important contribution to the mineralogy and lithology of the region, although it is weak in its petrology and geology, as would naturally be expected from the authors' line of research. This paper probably contains the best account of the mineralogy of the region which has yet been written. The general distribution of the rocks was shown on a map, but this is very imperfect.

The argillite was regarded as the oldest rock known in the region. (*l. c.*, p. 199.) The trappean rocks were called greenstone, greenstone porphyry, and green porphyry; the last two being regarded as varieties of greenstone. Attention was especially called to the globular disintegration of the greenstone, so well marked at some localities in this vicinity. (Proc. Bost. Soc. Nat. Hist., 1877, XIX., pp. 217–237.) They state that the greenstone has not been observed stratified, and that it overlies the argillite. It is also said to occur in large beds in the latter, while it is further claimed that it passes into syenite in places.

The felsite of the district was divided into two classes: petrosilex and porphyry. The petrosilex was regarded as a mineral, and the term applied only to the compact felsite, e. g. the so-called Saugus jasper. The banding of and irregular colored patches in the felsite were regarded simply as variations in the coloring of the mineral, and not stratification. This to a certain extent agrees with the results of modern investigation. Porphyry was the term applied to the felsite, whose base was held to be petrosilex, in which minerals were porphyritically embedded, especially quartz and feldspar. The feldspar was said generally to be in "rectangular crystalline grains, and the quartz in small rounded nodules." (*l. c.*, p. 204.) They further state that the "porphyry is unstratified in this vicinity, and is intimately connected with Sienite and Petrosilex, into both of which it passes." (*l. c.*, p. 205.)

The hornblendic and micaceous granites were classed as "sienite." The rock was regarded as principally a compound of quartz, feldspar, and hornblende, but it was said that "mica sometimes forms a large proportion of the mass; and hills of Sienite, of a fine structure, containing mica in quantity nearly equal to the other ingredients, prevail for a great extent, particularly at Danvers." It was also stated that "Sienite has not been observed stratified in this vicinity." (*l. c.*, p. 207.)

The amygdaloidal basalt or melaphyr was called Amygdaloid, and regarded as a rock having a homogeneous base. This base was supposed to have been originally cellular, and the cells afterwards filled with the minerals, "Petrosilex, Quartz, Feldspar, Epidote and Carbonate of Lime," forming the amygdules. The base was denominated "Wacke," which in common with petrosilex and basalt was held to be a simple mineral. The amygdaloid was said to be destitute of stratification, but to present sometimes an imperfect slaty structure. This rock was said to repose on, and to be associated with, the greywacke (conglomerate) of the vicinity.

The conglomerate so common in the vicinity of Boston was called greywacke, and said to be "composed of nodules of Petrosilex, Quartz, Argillite, Feldspar, Porphyry, and Sienite; some of these nodules approach, in magnitude, to rolled masses, and from these we find a gradual gradation to grains of sand." (*l. c.*, p. 210.) No stratification was observed in the greywacke and greenstone; argillite and amygdaloid are said to form beds in the greywacke. The amygdaloid was said to be intimately connected with the greywacke.

In 1818 there was also published Dr. Amos Eaton's "Index to the Geology of the Northern States, with a Transverse Section from Catskill Mountain to the Atlantic."

Like Maclure and the brothers Dana he follows the Wernerian system in a somewhat modified form, dividing the rocks into five classes: Primitive, Transition, Secondary, Superincumbent, and Alluvial.

He explains the presence of granite boulders in the vicinity of Boston and elsewhere as follows: —

> "The sienite stratum was formerly much thicker than at present. This aggregate has been long known to be strongly disposed to disintegration. It has dissolved and set loose the enduring granite, which now lies in loose blocks, with fragments of sienite attached to them, on the surface of the alluvial deposites."

This gives us the germ of the theory of the local origin of boulders by disintegration. Beyond this, the finding of a syenite boulder in front of the State House in Boston, and of fragments of argillaceous and graywacke slate near the same city, appears to be all that he knew of the geology of this district.

In the second edition, under date of 1820, argillite was thought t exist in the vicinity under the "deep alluvion" on account of the "large patches and fragments" which he found there (*l. c.*, p. 168). In his section Dr. Eaton represents hornblende rock as extending from Framingham to Boston, and dipping towards the sea at a gentle angle. Underlying this blanket of hornblende rock was gneiss, and then granite. Most of his information regarding the geology of Boston seems to have been taken from the Messrs. Dana's Outlines, referred to in the preceding pages.

According to the Rev. Elias Cornelius, the rocks at the eastern portion of the peninsula on which the city of Salem was built "are either a pure granite, or that variety of it called sienite, the hornblende of which is diffused in different proportions, from a few specks scarcely discernible, to very considerable quantities." (Amer. Jour. Sci., 1821, (1) III., p. 232.)

Dr. Thomas Cooper later remarked that "no person accustomed to volcanic specimens can look at the porphyries from the neighborhood of Boston, in my possession, and doubt of their volcanic origin." (Ibid., 1822, (1) IV., p. 239.)

In his Sketch of the Geology, &c. of the Connecticut, Prof. Edward Hitchcock states that epidotic and syenitic greenstones belonging to the Transition exist in the vicinity of Boston, and that dikes of basaltiform greenstone occur in the syenitic granite in the same region. (Ibid., 1824, (1) VII., p. 30.)

In a section given by Dr. Amos Eaton in his "Geological and Agricultural Survey of the District adjoining the Erie Canal," beginning at Boston and passing through Waltham, Weston, Sudbury, and Framingham, the country-rock is represented as being "hornblende rock including all its varieties." This rock is given as extending from Boston to midway between Framingham and Shrewsbury, and is figured as having a steep easterly dip. A patch of argillite is represented as horizontally underlying Harvard College and resting on the upturned edges of the "hornblende rock."

In the description of a section made by Prof. Edward Hitchcock, and placed at the end of the above-quoted work, the rocks in the vicinity of Boston are said to be syenite, argillite passing into greenstone slate, pudding-stone, amygdaloid, transition argillite, greenstone, and petrosiliceous porphyry. Veins of dark compact greenstone are said not to be uncommon in syenite and syenitic granite, in the vicinity of Boston. He cites Dr. J. W. Webster as authority for the statement "that the only rock ever found *in situ* in Boston" is syenite. A peculiarity of

Prof. Hitchcock's section is, that all the formations lying between Boston and a point some seventy miles west are represented as extending perpendicularly downwards.

Later, Prof. John W. Webster published his "Remarks on the Geology of Boston and Vicinity." (The Boston Journal of Philosophy and the Arts, 1824–25, II., pp. 277–292; 1825–26, III., pp. 486–489.) He states that the Boston peninsula exhibits no rock in place except at one locality. This was a light gray clay slate (argillite) found by digging to a considerable depth below the surface. The syenite seen, which had led to the belief that the rock of the peninsula was syenite, had been found to be a boulder. Winter Hill of Charlestown (now in Somerville) was said to be composed of clay slate passing on the north into hornblende slate. The dip was towards the north, at an angle of from 15° to 20°. These rocks contain "beds and veins of greenstone." The lowest rock on Prospect Hill, near Winter Hill, was regarded as a greenish compact feldspar,* in places strongly resembling some varieties of limestone. This rock passed into clay slate and dipped "to the south, inclining a little to the west, under an angle varying from 20° to 50°." This was overlain by trap, which it was thought once formed an extensive bed covering the slate. The Granite Street diabase of Prospect Hill was described and called a "sienitic greenstone." Likewise the diabase of the Powder-House, Somerville, and of Medford, is mentioned, and the boulder-like disintegration pointed out. The occurrence of slate north of the Powder-House was noted, together with trap overlying the slate or interposed between the strata.

The Roxbury conglomerate was described at some length, and said to pass "into coarse grau wacké, fine grained grau wacké, and grau wacké slate which becomes at last distinct clay slate." The components of the conglomerate enumerated were hornstone, quartz, compact feldspar, flinty slate passing to Lydian stone, porphyry, granite, clay slate, novaculite, serpentine, and nephrite. The occurrence of "trap veins or dikes" in the conglomerate was noticed. The conglomerate was said to pass into amygdaloid, the latter being the overlying rock. Another transition observed was in crossing the conglomerate of Dorchester, which was seen to acquire "a greater degree of compactness and uniformity of composition until within about three miles of the Blue Hills, where it passes into compact feldspar, and this last into hornstone." The Blue Hills were said to be composed principally of a "peculiar porphyry resembling some of the trachytes." This rock overlaid the syenite. The clay slate was thought to underlie all the other rocks to form the islands in Boston Harbor. The presence of slate in Quincy was noticed. The rock of Marblehead was designated as syenite. The Malden felsite was called porphyry, and that of Saugus a "bright red jasper." Of Nahant he remarks that the slate "has undergone a striking change from the presence of the huge veins of trap with which it is traversed in every direction." Prof. Webster previously had published a short account of the limestone of Stoneham, which he thought was probably in a bed. (Bost. Jour. Phil. and Arts, 1823–24, I., pp. 95, 96.)

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* This is the indurated argillite of that vicinity.

In the Report on the Geology, Mineralogy, Botany, and Zoölogy of Massachusetts, by Prof. Edward Hitchcock, published in 1833, considerable attention was given to the geology of Eastern Massachusetts. (See also Am. Jour. Sci., 1833, (1) XXII., pp. 1–70.)

The conglomerate of Brighton and elsewhere was denominated graywacke, said to be stratified, and "sometimes beautifully amygdaloidal." The amygdaloidal portion was regarded as "rather *wacke* than graywacke." The wacke "often forms the cement of graywacke." The localities of the amygdaloid were given as Brighton, Brookline, Newton, Needham, Hingham, and Saugus. (*l. c.*, pp. 33, 34.) It can be readily seen from reading President Hitchcock's report that he holds that all the amygdaloidal melaphyr above mentioned passes into the conglomerate, the former being only a variety of the latter. The amygdules were according to him formed by fusion, except in some cases where they were formed by infiltration. (*l. c.*, pp. 248–262.) The argillite of Nahant he regards as part of the graywacke formation belonging to the Transition. The argillite there he calls flinty slate, and appears to hold that the induration was caused by the trap veins passing through it. He also remarks : —

> "The slaty structure is rarely lost, except at the junction of the greenstone and slate, where the two rocks are so intimately blended, that it is not easy to fix upon the spot where either of them commences. This corresponds with the opinion of Dr. Maculloch, that nothing but the requisite degree of heat is necessary to convert argillaceous slate into greenstone." (*l. c.*, p. 265.)

The argillite (argillaceous slate of Hitchcock) in the vicinity of Boston was described with the graywacke formation, although President Hitchcock was inclined to make it older.

The limestone of Stoneham, Newbury, and Chelmsford, he held to be in beds, modified by the action of granite and syenite, which had obliterated the lines of stratification. (*l. c.*, pp. 308–313.)

The unstratified rocks were assigned an igneous origin without exception. They were regarded as having been formed during diverse ages, the author holding that

> "their intrusion among the stratified rocks affords an important clue for determining their relative ages. It is obvious, however, that the intrusion of the former among the strata of the latter, only proves that the unstratified rock was formed posterior to the stratified one."

While we believe that the above quotation from President Hitchcock's work is essentially sound in its views, it will be seen in the sequel that considerable work has been done in this vicinity from a diametrically opposite point of view.

President Hitchcock further held that all these rocks were

> "merely varieties of the same melted mixture, whose peculiarities resulted from the modes in which they were cooled, and crystallized, and intruded among the stratified rocks. . . . . On this supposition we are no longer surprised to find it impossible to draw any definite line between the different varieties, nor to find them all united in the same mountain mass."

He inclined to the opinion, that all the unstratified rocks of Massachusetts belonged to a single family, but concluded to treat of them all under four divisions, viz. greenstone, porphyry, syenite, and granite. The order of production according to him, beginning with the lowest, is as follows: granite, syenite, porphyry, and greenstone. He further states: —

> "Porphyry, however, passes by insensible gradations into sienite; but the change commonly takes place in a vertical and not in a horizontal direction." (*l. c.*, pp. 402–404.)

The greenstone was regarded as a mixture of hornblende and feldspar, although some at Nahant was thought to contain augite. This rock was said to be mixed with syenite in every conceivable mode, and to pass into it and into granite. The former rock was in general the younger, although cases were observed in which the latter held fragments of the greenstone. A special case is cited, a little west of Marblehead village, and explained as follows: —

> "They certainly appear as if the greenstone had been partially melted down in the granite; though the heat was not great enough to complete the fusion. Or rather, may it not be probable, that the perfect fusion of the rock out of which these unstratified ones were produced, gave rise to the granite; while those portions that were not so entirely fused as to admit of entirely new and perfect combinations and crystallizations, might have formed those portions of the rock which I call greenstone."

It appears from his remarks in connection with this, that in his opinion a more or less perfect fusion of the same materials may have been the principal cause of the production of greenstone, syenite, porphyry, and granite from them.

The unstratified rocks were said to "occur in three modes: first, as protruding irregular masses; secondly, as overlying masses; and thirdly, as veins." The greenstone he held to be principally of the first class, but considered that it also occurred in veins. In regard to these points he thus expresses himself:

> "Wherever I have seen this rock associated with the graywacke and argillaceous slate in the eastern part of the State, it either occupies veins, or protrudes itself in some other form, among, or between, the strata. . . . . It has there also the appearance of being regularly interstratified with the slate. But I am satisfied that this is a deception; that is to say, these supposed beds are connected with some unstratified masses. Yet I think it extremely probable that some of the greenstone in the vicinity of Boston has resulted from the fusion of clay slate; and perhaps it is possible that a particular portion of the slate might be converted into greenstone, while that around it might remain but little changed; and in such a case, the altered rock might at the surface appear interstratified with the other."

On Nahant the presence of two sets of trap dikes was noticed, and it was held that the slate was in the form of a clay at the time of the intrusion of the greenstone which altered it. The apparent distinct stratification (jointing?) of some greenstone on this promontory was regarded as the result of a concretionary structure. Part of the veins (dikes) were said to run parallel with the strata, and it was thought that they would be regarded by some geologists as being regularly interstratified with the slate. President Hitchcock gives the following as the reasons why he holds the greenstone to be of igneous origin:

1. "The resemblance in external characters between some varieties of our greenstone and the products of existing volcanoes."
2. "The columnar structure of greenstone."
3. "The irregular manner in which greenstone is intruded among stratified rocks."
4. "The Mechanical effects of Greenstone upon the Stratified Rocks."
5. "The Chemical effects of Greenstone upon the Stratified Rocks."

These views were illustrated by examples. (*l. c.*, pp. 404–442.)

The porphyry is divided into four classes: 1. Compact Feldspar; 2. Antique Porphyry; 3. "Porphyry with a base of compact Feldspar and two or more minerals embedded"; 4. Brecciated Porphyry. The last he describes as being "composed of angular fragments of porphyry and compact feldspar, re-united by a paste of the same materials, which is itself also porphyritic. Hence it appears that there must have been an original formation of these rocks (compact feldspar and porphyry) which was subsequently broken up, either by the mechanical agency of water, or the mechanico-chemical agency of heat, redissolving and mingling the materials."

Of the geological position he remarks : —

"Am I asked whether the porphyry of Massachusetts belongs to the Primitive, Transition, or Secondary Class? I reply that it belongs to none of them, but is a member of a series of rocks consisting of granite, sienite, porphyry, and greenstone, which have been protruded through or among the stratified rocks, subsequent to their deposition. . . . . The mere existence of these rocks, therefore, among those of any particular stratified class, does not prove that they were produced at the same epoch; it rather proves that the unstratified rock was of subsequent production. . . . . I have never met with an instance in which this porphyry was exhibited in juxtaposition with any stratified rock: except as already remarked, the compact feldspar succeeds to the graywacke as an older rock and gradually passes into porphyry. This porphyry, however, is associated, both on the north and south of Boston, with sienite; and in all cases, so far as I have observed, *the porphyry lies above the sienite*, and there is a gradual transition between the two rocks."

The compact feldspar was considered to have been derived from the melting of common feldspar or albite, in connection with other minerals. He remarks as follows in regard to this compact feldspar : —

"That it does result from this change in common feldspar, I can hardly doubt, when I often see specimens that have not entirely lost their foliated structure, being intermediate between the two minerals. . . . . It is not uncommon to meet with specimens of porphyry that exhibit traces of an originally slaty structure in all or a part of the materials composing it. This clearly points us to a slaty rock as the source from which porphyry was derived. And sometimes fragments of this rock, along with fragments of compact feldspar, flinty slate, &c. are scattered through the mass as if partly melted down; very much as fragments appear in the slag of a furnace. They seem to be all but incorporated with the paste, and the whole mass presents an appearance of a more perfect chemical union than any rock resulting from aqueous agency ever exhibits, unless it be entirely crystalline. . . . . The gradual passage of this rock into sienite, without any apparent change of ingredients, seems to indicate that the peculiarities of porphyry did not result chiefly from the nature of the materials employed in its production." (*l. c.*, pp. 442–451.)

Under the term syenite President Hitchcock included "all the varieties of rock, between greenstone and porphyry on one side, and common granite on the other, into whose composition hornblende enters." His varieties of syenite were six, of which only the first five occur in the district under discussion here. It would seem that he included under the name syenite many diabases as well as hornblendic granites. The division of the rock into parallel portions observed in one locality on Cape Ann he regards as pseudo-stratification (concretionary structure), and not real stratification. The syenite was said to pass by insensible gradations into granite on one side, and into greenstone or porphyry on the other, the author remarking as follows: —

> "Or when these rocks are wanting, some of the stratified rocks, such as hornblende slate, graywacke, or new red sandstone repose upon it. .. . . In all cases where this rock occurs, we find it between the oldest granite and greenstone, or the earlier stratified rocks. Hence I infer that a portion of the materials of which granite is composed, under certain circumstances were converted into sienite, and that these circumstances existed generally in that portion of the melted granite nearest the newer stratified rocks. Or if we suppose it erupted at a different epoch from the granite, certain causes always forced it upwards between the granite and the newer rocks. Or if we suppose it to have resulted from the melting down of the stratified rocks, then perhaps their more or less perfect fusion produced the difference which we find between granite and sienite."

The syenite is said to penetrate "sienite of a different variety, or greenstone." . President Hitchcock thought that the evidence in favor of its igneous origin was not strong, yet he held that view. (*l. c.*, pp. 451–465.) A second and revised edition of this report was published in 1835, but his views remained essentially unchanged.

In 1838 was published President Hitchcock's "Report on a Re-examination of the Economical Geology of Massachusetts." In this the existence of the Lynnfield serpentine was pointed out (pp. 137, 138).

President Hitchcock's Final Report was published in 1841, and in it certain changes were made. The graywacke was subdivided into the Coal Measures, Old Red Sandstone, and Graywacke. The last comprised the conglomerates about Boston Harbor and in some other localities (*l. c.*, p. 534). The argillite in the vicinity of Boston was still included in it, although lower in the series. Under the head of "Metamorphic Slates" were classed among other formations "Aggregates of Porphyry," "Varioloid Wacke," and the "Flinty Slate of Nahant." Of the first he says: —

> "The best example . . . ., perhaps, is in Hingham, a little west of the village; and in Cohasset, at the head of Nantasket Beach. At the latter place is a coarse breccia, or conglomerate, which is chiefly made up of fragments of porphyry reunited by a cement of the same materials, and is sometimes almost

reconverted into compact porphyry. . . . . At the head of Nantasket Beach is another metamorphic rock, lying contiguous to the breccia just mentioned. . . . . I incline to the opinion that it was originally a hard slate, like that on Nahant, and the Brewster Islands, which has been very much changed and filled up with veins of epidote, by the action of heat. Some of it appears as if converted into a sort of compact feldspar." (*l. c.*, pp. 547, 548.)

The latter rock he described in the Report for 1833 (p. 255) as consisting of "fragments of gray and yellowish green compact feldspar, united by an unknown dark-colored cement."

The "varioloid wacke" is the amygdaloid of most writers on the geology of Eastern Massachusetts, and, as in 1833, President Hitchcock holds that it passes into and "is only a metamorphic variety of the graywacke formation." (Final Report, 1841, pp. 548, 549.) In this Report he held that "the different unstratified rocks appear to be the result of volcanic agency exerted at different periods under different circumstances," and gives reasons for this view, which in part at least appear to be sound. He further remarks: —

> "The greater degree of crystallization in the older unstratified rocks may be explained, by supposing a more perfect fusion of the materials than in recent lavas, and greater slowness in cooling, under perhaps the more powerful pressure of a deep ocean." (*l. c.*, pp. 790, 791.)

He advances two theories for the origin of the "Primary Stratified Rocks."

> 1. "The stratified primary rocks are merely the detrital or fossiliferous rocks altered by heat. As these accumulated at the bottom of the ocean, being much poorer conductors of heat than water, they would confine the internal heat that was attempting to escape by radiation, until it became so great as to bring the matter into a crystaline state: but not great enough to produce entire fusion, so as to destroy the marks of stratification."
>
> 2. "This hypothesis supposes the primary stratified rocks to have been formed partly in a mechanical and partly in a chemical mode, by aqueous and igneous agency, when the temperature of the crust of the globe was very high, and before organic beings could live upon it."

President Hitchcock seems indeed to incline towards the second theory. (*l. c.*, pp. 796–798.)

In 1839 Mr. William Prescott's "Sketch of the Geology and Mineralogy of the Southern Part of Essex County, in Massachusetts," was published. (Journal of the Essex Co. Nat. Hist. Soc., 1852, I., pp. 78–91.) The rocks were described as gneiss, syenite, greenstone, porphyry, silicious breccia and brecciated porphyry, puddingstone, amygdaloid trap, and magnesian serpentine, or verd antique marble. The syenite was said to pass into greenstone often by insensible shades. This paper locally is of considerable value. The red felsite of Saugus was described as jasper.

In 1854 the limestones of Eastern Massachusetts were referred to the Devonian by Dr. Hunt, who remarks as follows: —

> "In the fourth class we include the crystalline limestone of eastern Massachusetts, which occurs in a great number of places in the towns of Bolton, Boxborough, Chelmsford, Carlisle, Littleton, Acton, Natick and Sherburne. It appears according to Hitchcock, in interrupted lenticular masses, lying in the gneissoid formation, or in the hornblendic slates, and occasionally presenting distinct marks of stratification. Still farther east at Stoneham and Newbury, we find crystalline limestone, sometimes magnesian, in irregular masses, lying in a rock intermediate between syenite and hornblende slate. Serpentine is found with that of Newbury; and at Lynnfield, a band of serpentine has been traced two or three miles N. E. and S. W. . . . . We have now to inquire as to the geological age of this great mass of crystalline rocks which is so conspicuous in Eastern New England. . . . . When we consider the geographical position of the Upper Silurian rocks in the Connecticut valley on the one hand, and the coal fields of southeastern Massachusetts on the other, we can scarcely doubt that the intermediate gneissoid, and hornblendic rocks, with their accompanying limestones, are the Devonian strata in an altered condition." (Am. Jour. Sci., 1854, (2) XVIII., pp. 198, 199.)

As late as 1863 the same view of the age of these limestones was held; while in 1861 Dr. Hunt especially stated, that we recognize nothing in New England or southeastern Canada lower *than the Silurian system*." (Am. Jour. Sci., 1861, (2) XXXI., p. 403; 1863, XXXVI., p. 225; Geology of Canada, 1863, p. 592.)

In 1856 the first definite knowledge of the actual geological position of any of the rocks in the vicinity of Boston was obtained. Specimens of a trilobite, belonging to the genus *Paradoxides*, and a characteristic fossil of the Primordial, or Potsdam group of the Lower Silurian, had for many years been in the hands of scientific men in Boston; but the locality from which they had been obtained was not known. Finally, in 1856, the attention of geologists was called to these trilobites by the proprietors of a quarry in the argillite at Braintree, and the first notice of the occurrence of these fossils, and of their true locality, was given to the public by Prof. W. B. Rogers. (Proc. Bost. Soc. Nat. Hist., 1856, VI., pp. 27–30, 40, 41, 217; Am. Jour. Sci., 1856, (2) XXII., pp. 296–298; Proc. Am. Acad., III., pp. 315–319.)

Professor Rogers describes the argillite as being included between large masses of igneous rock, or syenite, and a dipping N. 20° W., at an angle of about 45°. Dr. C. T. Jackson, later, gave the dip as to the north, at an angle of 50°. (Proc. Bost. Soc. Nat. Hist., 1856, VI., pp. 42–44.)

The next year, Mr. Isaac Lea, however, on examining the position of the fossils in the rocks, concluded that the dip was to the south, and to the amount of 68°. (Proc. Phil. Acad. Nat. Sci., 1857, IX., p. 205.) This latter appears, beyond doubt, to have been a correct statement of the direction of the dip, if not of its amount.

Dr. Hunt, in 1866, in his paper on the Laurentian Limestones, remarks of the crystalline limestones of Bolton and the adjoining towns in Eastern Massachusetts, that they

> "resemble in geognostic and mineralogical characters, those of the Laurentian system. There are however not wanting reasons for supposing them to belong to a more recent geologic period, and the facts recently observed in Bavaria . . . . show, what was antecedently probable, that similar mineralogical characteristics may be found in crystalline limestones of very different ages." (Geol. of Canada, 1863–66, p. 197.)

This was reprinted without change in 1871, in the revised edition published in the Report of the Regents for New York. (See also Am. Jour. Sci., 1854, (2) XVIII., p. 200.)

In 1862, Mr. T. T. Bouvé claimed that he had traced, especially in Hingham, the passage of the conglomerate into a compact, homogeneous, almost jaspery rock. (Proc. Bost. Soc. Nat. Hist., 1859, VII., p. 183; 1862, VIII., p. 57.)

In 1867 Prof. Chas. H. Hitchcock remarked that there was reason to believe that the gneiss and hornblende schist of Andover belonged to

> "Eozoic ages, perhaps as old as the Laurentian. . . . . The evidence consists chiefly in the fact that pebbles of the syenite, which is newer than the schist, occur in the Paradoxides slates near Boston, along with red jasper, green porphyry, and other rocks associated with the syenite. These slates form the lowest member of the Paleozoic series; hence the rocks from which the pebbles were derived are older than the Silurian, and must be Eozoic. Lithologically they resemble the Laurentian gneiss and syenite, in the typical localities." (Proc. Essex Institute, 1867, V., pp. 157–160.)

Professor Hitchcock probably had in mind the argillites and conglomerates, of whose age nothing definite is known, for in the Braintree argillite containing fossils, so far as the published records show, no such pebbles have been found by the numerous observers who have examined it.*

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* Dr. Wadsworth has repeatedly examined the Braintree locality with a like negative result, so far as the occurrence of pebbles is concerned.

In the Bulletin of the Essex Institute, August 26, 1869, Vol. I. p. 106, the following report occurs: —

> "Professor T. Sterry Hunt of Canada gave a geological description and history of the New England granite formation. The investigation of the last twenty years had gone very far to destroy the commonly received notion that granite was the foundation of all other rocks. They were beginning to learn that instead of the granites being the substrata of the globe, they were rather secondary or derived rocks, — that they were once great beds of gravel or sandstone which had subsequently become crystallized. After speaking of the probable age of New England granites, Professor Hunt said that in walking along the shore at Rockport, he could see that the granites were distinctly stratified with alternations of sandstone at different periods. This clearly showed their sedimentary origin, and probably identified them as being the same as the granites north and south, and thus enabled them to class them among the Devonian rocks. Perhaps ten thousand or fifteen thousand feet beneath them might be beds holding fossils of the Silurian type, — the same beds, perhaps, as those cropping out at Braintree. As compared with the rocks at Braintree, the granites probably were of very recent origin. From careful analysis it was ascertained that the Rockport granite contained traces of living organisms. He would mention that with reference to aerolites, chemists had found in them traces which by them were regarded as certain evidence of the remains of organic life."

October 19, 1870, Dr. Hunt said that the granites of Cape Ann and of Quincy were probably intrusive, (Proc. Bost. Soc. Nat. Hist., 1870, XIV., p. 46,) which agrees with the view advanced by him in a paper read before the American Association for the Advancement of Science, August 20, 1870. (Am. Jour. Sci., 1871, (3) I., p. 85.) In 1873 the granites of Rockport were stated by him to be distinctly eruptive. (Proc. Bost. Soc. Nat. Hist., 1873, XV. p. 262.) These statements, then, according to Dr. Hunt's published views (Chemical Essays, p. 9), necessitate a depression of the sediments, out of which the granite was formed, into the *solid* earth to the zone of igneo-aqueous fusion, where the eruptive granite was formed. Part of the original sandstone, however, remained in this zone unchanged; while beneath, at a depth of ten or fifteen thousand feet lower, the Silurian rocks retained their original character, their fossils remaining unaffected; and this took place in the "same beds, perhaps, as those cropping out at Braintree," the rock at that place being, as is well known, an easily fusible argillite. Then this granite was raised again to the surface, thus carrying the argillite unmetamorphosed twice through the zone of igneo-aqueous fusion.

In November, 1869, Mr. E. Bicknell announced that *Eozoön Cana-*

dense had been found in the serpentine (limestone) quarry at "Devil's Den," Newbury. Prof. Hyatt then remarked that "the rocks of this county [Essex] had been hypothetically referred to the lowest known series of Laurentian strata"; but that this was the first instance "in which any positive evidence has been produced of their actual age." (Bull. Essex Institute, 1869, I. pp. 141, 142; American Nat., 1869, III., pp. 498, 499.)

In 1869, Prof. N. S. Shaler remarked: —

> "There can be no doubt that the syenites, which make up so large a part of the exposed rocks of Eastern Massachusetts, are the oldest materials found in this region. . . . . The most remarkable fact which has come under my observation is the existence of planes of separation in this syenite, which cannot be referred to joints. . . . . That I am not mistaken in referring these fractures to bedding, is, I believe, abundantly proven by the details of structure of the syenite itself, as well as by the relations it bears to the unquestionably stratified rocks which rest upon it. . . . . There are visible on the surface of considerable sheets of this rock, laid bare in the Mitchell quarry near Quincy, splitting along what I believe to be the plane of stratification, markings indistinguishable from ripple marks. . . . . If these syenites were of igneous origin, if they had been poured out before the deposition of the adjacent stratified beds, or thrust through them in a state of fusion, we should expect to find the usual marks of such actions. In the first of these cases the later sedimentary deposits would be found lying unconformably upon the syenite without any indication of transition; in the second we should expect to find a clear line of contact between the syenite and the sedimentary rocks, such as is always to be found where an intrusive mass of trappean matter cuts more ancient rocks. What we do find is that the imperfect bedding of the deeper portions of the syenite becomes more and more clearly defined as we pass towards the exterior of the mass, and gradually passes into unquestionably sedimentary rock. Every stage of this transition is not clearly seen, but enough is visible to satisfy any one that it really exists. The first rocks of quite unquestionable stratified origin, lie directly to the north of the Quincy syenite hills, and consist of clearly bedded sandstones, approaching quartzites in their character. . . . . Their general dip is northerly, with a variable angle of inclination which may be roughly averaged at twenty degrees. . . . . Running the same north course across the break, we come upon the lowest of the Braintree series. . . . . Its dip corresponds with the general inclination observable in the supposed stratification of the syenite, as well as that of the quartzites immediately above it. The whole of this Braintree series is fossiliferous, ... and although much changed by metamorphic action, it is easily perceived that the whole set of beds contains no trace of shore deposits. Immediately beyond the exposure of the Braintree beds at Hayward's Landing, a dislocation has brought the thin bedded quartzites again to the surface. The alteration in these is so great that

the rock has assumed something of the appearance of gneiss, and would by some be classed in that group of rocks. . . . . The uniform dip away from the Quincy Hills, shown by all the stratified beds on their flanks, may be regarded as sufficient proof that their elevation came after the deposition of these beds." (Proc. Bost. Soc. Nat. Hist., 1869–71, XIII., pp. 172–178.)

While to one not acquainted with the geological structure of the region described, Professor Shaler's paper may appear conclusive; the facts, that the granite presents exactly the same intrusive relations to the argillite that he says it should have if eruptive; that he mistook for sandstones and quartzites the Quincy granite itself; that the fossils in the argillite show that its dip is diametrically the opposite of the one he has assumed; that his supposed ripple-marks were the not uncommon wavy fracture of granite; and finally that his assumed stratification planes are joint or structure planes, — leave his conclusions without any foundation.*

Professor Shaler points to the relations between the argillite and conglomerate as exposed while the excavations were being made for the construction of the Chestnut Hill Reservoir. There he found that the argillites lay beneath with conglomerate overlying, then more argillite and above this the conglomerate, indicating it as probable that the argillites and conglomerates in the vicinity of Boston form the same series of beds, which he considered to belong to the primordial era. (*l. c.*, p. 176.)

In 1870, Dr. Hunt, on account of the finding of *Eozoön Canadense* in limestones at Newbury (erroneously said to be in the adjoining town, Newburyport) and Chelmsford, regarded the associated rocks as being of Laurentian age, saying: —

> "These specimens from Chelmsford, it should be said, have been examined and satisfactorily identified by Dr. Dawson. The argument from mineralogical and lithological resemblances in favor of the Laurentian age of the limestone in question is therefore now supported by the undoubted presence in them of *Eozoön Canadense*."

The rocks about Newbury, which it will be recollected were united by Prof. C. H. Hitchcock to the Cape Ann and Quincy hornblendic granites (syenites), Dr. Hunt regards as unlike the latter. (Am. Jour. Sci., 1870, (2) XLIX., pp. 75–78.)

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* In the preceding paper of Professor Shaler the misnomer of "Cambridge slates" was applied to the argillites so well exposed in Somerville, and which properly should have been called by the name of that city instead of Cambridge. The truth is, that the locality from which they were named was erroneously supposed to be in Cambridge, when in fact it is in Somerville. This locality was again erroneously said to be in Cambridge in Professor Shaler's "Question Guide to the Environs of Boston," 1875, p. 20. No exposure of the argillite is known to exist in Cambridge, although it has been found there by digging.

In a paper published in 1870, but said to have been read before the American Association in August, 1869, Dr. Hunt remarks: "The gneiss of Eastern Massachusetts is, as I have recently found, in part of Laurentian age." (Am. Jour. Sci., 1870, (2) XLIX., p. 184.) Again, the same year, the "diorites and porphyries" at Newburyport, Salem, Lynn, and Marblehead were referred to the Cambrian, which Dr. Hunt at that time appears to have regarded as the equivalent of the Huronian. (Am. Jour. Sci., 1870, (2) L., p. 89.) Further, of his Terranovan series he states: —

> "The micaceous and hornblendic schists, with interstratified fine grained whitish gneisses (locally known as granites) which I have seen in Hallowell, Augusta, Brunswick and Westbrook, in Maine, appear to belong to the same series; which will also probably include much of the gneiss and mica-schist of Eastern New England. If this upper series is to be identified with the crystalline schists which, in Hastings County, Ontario, overlie, unconformably, the Laurentian, and yet contain *Eozoon Canadense*, the presence of this fossil can no longer serve to identify the Laurentian system. To this lower horizon however, I have referred a belt of gneissic rocks in Eastern Massachusetts, which are lithologically unlike the present series, and identical with the Laurentian of New York and Canada." (*l. c.*, p. 88.)

In October, 1870, Dr. Hunt stated regarding the geology of Eastern Massachusetts, that

> "the rocks which we have seen may be considered in three classes. A, the crystalline stratified rocks; B, the eruptive granites; C, the unaltered slates, sandstones and conglomerates. The former of these may be separated lithologically into two divisions; the first being the quartzo-feldspathic rocks. Among these are included the felsite-porphyrites of Lynn, Saugus and Marblehead, with their associated non-porphyritic and jasper-like varieties. . . . . Associated with them is a granular quartzo-feldspathic rock, which is often itself porphyritic, with feldspar crystals, and sometimes appears as a fine grained syenitic or gneissoid rock, often distinctly stratified. . . . . These rocks are seen intimately associated with the porphyry on Marblehead Neck, also in Marblehead, and underlying the argillites of Braintree and Weymouth. The second division of the rocks of class A includes a series of dioritic and chloritic rocks, generally greenish in color, sometimes schistose, and frequently amygdaloidal. . . . . This series holds a bed of dolomite at Stoneham, and serpentine in Lynnfield, ... the greenstones of Dr. Hitchcock . . . . ; and also his varioloid wacke, under which name he describes the green and chocolate-colored amygdaloidal epidotic and chloritic rocks of Brighton, and the somewhat similar rocks of Saugus. . . . . I regard these two types of rocks as

forming parts of one ancient crystalline series, which is largely developed in the vicinity of Boston, and may be traced at intervals from Newport to the Bay of Fundy, and beyond. To this same series I refer the great range of gneissic and dioritic rocks with serpentines, chloritic, talcose and epidotic schists which stretches through western New England. These ancient rocks are in various places penetrated by intrusive granites, which are generally more or less hornblendic — the syenites of Hitchcock and others. . . . . In this vicinity, besides the granites of Cape Ann and of Quincy, which probably belong to this class, examples of intrusive granites (or syenites) are well seen in Stoneham and in Marblehead, where they cut the greenish chloritic rocks, and on Marblehead Neck, where they are erupted among the felsite-porphyries. In all these places the phenomena of disruption and enclosure of fragments of the broken rock in the granite are well seen, the lines of contact being always sharp and well-defined. . . . . All of these rocks, the granites included, are on Marblehead Neck traversed by dykes of intrusive greenstone, which are sometimes very similar in aspect to certain of the bedded diorites of A. Of the rocks of class C, the unaltered argillites of Braintree, holding a primordial fauna, were observed by Prof. Shaler and myself to rest directly upon a hard porphyritic felsite of the ancient series. . . . . Reddish granulites directly underlie the black argillites of Weymouth, and the quartzites with conglomerates and argillites of Chestnut Hill Reservoir, and of Brighton near by, are in several places observed in contact with the old dioritic and epidotic rocks already noticed. The Roxbury conglomerate was observed to contain pebbles of the felsite-porphyries, diorites and intrusive granites of the older series, besides, as already remarked by Hitchcock, fragments of argillaceous slate. In this connection may be noticed a remarkable recomposed rock long since correctly described by the same careful observer, as an aggregate of broken-up and recemented felsite-porphyry. . . . . He observed it at Hingham and Cohasset, and Mr. Hyatt has since found it on Marblehead Neck, resting directly on the parent rock, and very firmly cemented. The unequal weathering of the surface, however, clearly shows both its conglomerate character and the inferior hardness of the cement. . . . . The fact that the primordial strata of Braintree have suffered no metamorphism is the more significant, since the beds of similar age in New Brunswick and Newfoundland rest unconformably on crystalline strata supposed to belong to the same ancient series that underlies the Braintree beds, and are, like these, unaltered sand and mud rocks." (Proc. Bost. Soc. Nat. Hist., 1870, XIV., pp. 45–49.)

This paper of Dr. Hunt's secured an amount of acceptance amongst the local geologists far beyond that to which it was entitled; especially when it is remembered that it is based on simple assertion, without any evidence in support of the positions taken. Moreover, these views were largely in opposition to his life-long teachings, down to 1869, and concerning which statements had been made as positive in character as those of an opposite nature here upheld. From this time onward, however, most of the geological papers relating to Eastern Massachusetts were based on the views of Dr. Hunt as here presented. It may be noticed that the Quincy granite near the Braintree argillite quarry, which Professor Shaler regarded as a quartzite or sandstone, Dr. Hunt calls the same as the Marblehead felsite.

In Mr. Walling's Atlas of Massachusetts, published in 1871, Prof. C. H. Hitchcock gave a Geological Description of the State (pp. 17–23). He writes : —

> " In New England the older strata have been greatly *metamorphosed*, i. e., have been transformed from the original sedimentary sandstones, clays, and limestones into granite, gneiss, schists, slates, and other crystalline rocks ; and during the process of change the remains of the primeval animals and plants have been mostly obliterated."

To the Eozoic formation he refers

> " the syenite and porphyry of Eastern Massachusetts ; and possibly the gneiss and granite of Plymouth and Bristol counties, and the gneiss and hornblende schist of Middlesex county. . . . . Associated with the Paradoxides slates of Hingham, is a conglomerate composed of pebbles of syenite and porphyry, like the ledges of these rocks occupying so much of the area in Essex, Middlesex, Norfolk, and Plymouth counties. The inference is irresistible, that these unstratified rocks existed as ledges before the birth of the trilobite, occupying the very oldest Paleozoic bed, and therefore they must be of Eozoic age. Lithologically, there is a slight resemblance between some of the porphyritic rocks and the Huronian group of Canada and Michigan."

Prof. Hitchcock is in error here, since the age of the Hingham argillite is not known, and if it were, the finding of fragments of an eruptive rock in a sedimentary one is no proof of difference in geological age.

In his Notes on Granitic Rocks Dr. Hunt says : —

> " Felsites and felsite-porphyries are well known in Eastern Massachusetts at Lynn, Saugus, Marblehead and Newburyport. . . . . These rocks are throughout this region distinctly stratified, and are closely associated with dioritic, chloritic and epidotic strata. They apparently belong, like these, to the great Huronian system." (Am. Jour. Sci., 1871, (3) I., p. 84.)

Later, Prof. A. Hyatt remarked : —

> "The porphyry of our vicinity, whether Lynn, Marblehead or Newburyport is a recomposed rock, a conglomerate composed of more or less rounded pebbles of more ancient banded porphyry. . . . . We meet in the neighborhood of Newburyport with a transition rock made up partly of porphyry, and then with stratified diorites and slates, which surround the porphyry outcrop on the sea-face. . . . . The northwesterly dip, and northeasterly strike of these diorites and slates, and the presence of slate rocks in Topsfield and Middleton,

are difficult to account for unless we imagine the porphyries to be interstratified with them. The succession of the strata in this part of the country then would be Eozoönal limestones and serpentines, then slates, then the porphyries of Kent's Island and Lynn, then slates and diorites, and lastly, the porphyries of Marblehead Neck. Either this is the explanation or else we have several anticlinal axes or folds in the porphyry. In either case all the porphyries are probably older than the Eozoönal rocks of Newburyport, and underlie them. The porphyry of Marblehead Neck has the stratified micaceous rocks . . . . lying upon its southeastern face, with dip and strike precisely conformable to the more ancient shore-line formed by the porphyry itself. The porphyry of Lynn has upon its eastern face the outcropping edges of an enormous overflow of igneous granite. . . . . In fact, all the difficulties of the survey have arisen from the enormous sheet, or rather, sheets of igneous rocks, for there seems to have been several which overspread the surface of the country." (Bull. Essex Inst., 1871, III., pp. 49–53.)

Dr. Hunt, in reply to Prof. Hyatt's communication, remarked as follows: —

"I have expressed the opinion that the porphyries of the eastern coast of Massachusetts are stratified rocks, belonging, together with their associated diorites and slates (greenstones, chloritic and epidotic rocks), to the Huronian system, or Green Mountain system. As regards the limestones with Eozoön, from eastern Massachusetts, which in the *American Journal* for Jan., 1870, I referred to the more ancient Laurentian system. I have in that same journal for July, 1870, pointed out the fact that the Eozoön of Hastings county, Ontario, occurs in a series of crystalline schists which I consider newer than the Huronian, and the equivalent of the White Mountain gneisses and mica-schists, so that, as I there remark 'the presence of this fossil can no longer serve to identify the Laurentian system.' . . . . It will therefore remain for farther study, to determine how far the crystalline limestones of eastern Massachusetts belong to the Laurentian, and whether some of them are not included in one or the other of the newer systems of crystalline schists. The porphyry conglomerate noticed by the late President Hitchcock and described by Prof. Hyatt, are referred to in my paper of last October, mentioned above. This rock is, I conceive, to be distinguished from the old Huronian porphyry, on which it often reposes, and from the ruins of which it is derived." (Bull. Essex Inst., 1871, III., pp. 53, 54.)

If the reader will refer to our quotation of Dr. Hunt's paper relating to the Eozoön, or to the original (Am. Jour. Sci., 1870, (2) L., p. 88), he will see that the remark regarding the value of that supposed fossil was a *hypothetical*, and not a *positive* one, as Dr. Hunt now claims it to have been. In connection with the above quotation from the Bulletin of the Essex Institute it may be interesting to remember that a little over a year later Dr. Hunt denied that he had held that the White Mountain series was younger than the Green Mountain or Huronian series. (Am. Jour. Sci., 1872, (3) IV. p. 51.)

In his address before the American Association, Dr. Hunt still held that the gneisses and crystalline limestones of Chelmsford, etc. were Laurentian, and said: —

> "The uncrystalline argillites and sandstones, holding Paradoxides, at Braintree, ... overlie unconformably crystalline schists of the second series," (Huronian or Green Mountain). (Proc. Am. Assoc. Adv. Sci., 1871, XX., pp. 10, 32.)

In 1875 Mr. W. W. Dodge classified the rocks of Eastern Massachusetts as follows (Proc. Bost. Soc. Nat. Hist., 1875, XVII., pp. 388–419): —

I. Crystallines.
II. Stratified Rocks { A. Slates.
  B. Conglomerates.

Of the crystallines he says: —

> "They underlie unconformably strata holding Paradoxides, etc., and probably formed hill or island ranges very early in the history of this continent. . . . . For the most part, metamorphism has been so complete that these rocks have lost almost entirely their probable original character."

Of the syenite he states: —

> "The abundance of quartz seems to point rather to metamorphic than igneous condition, and there is probably no doubt that they are chiefly of sedimentary origin. . . . . Above Spy Pond in Arlington, there are slaty rocks which pass through fine grits to coarse sienite by various stages. So, too, in Medford."

Under the term "porphyry" he makes four divisions, and thinks that some of the slates may have been so altered as to closely resemble porphyry. He appears to hold that all the rocks included under the term "crystallines" are of sedimentary origin, and have acquired their present character by metamorphism. The eruptive rocks of this region Mr. Dodge holds to have been derived from the "crystallines," remarking: —

> "As a matter of fact, so close is the resemblance in chemical composition, appearance and minerals developed in them, of the eruptives among the slates and conglomerates, to the more fusible portions of the crystallines, that it seems almost unreasonable to doubt that the former were derived from among deep lying masses of the latter."

Of the Brighton melaphyr (amygdaloid) he states: —

> "Whether these rocks as a whole are of the crystalline stratified class, or whether they have undergone such change as to entitle them more appropri-

ately to a different name, this is certain, that some of them are found cutting the slate and conglomerate, and poured out over them, and that near the contact the slate is greatly hardened."

Of the "stratified rocks" Mr. Dodge remarks: —

"Between the older rock bands described lie certain more recent and more clearly stratified rocks. The more recent age of these is shown beyond dispute by their position in relation to the underlying crystallines, as well as by the fact that they are composd of detritus of the latter, which may not only be so recognized, but even may at times be referred to the source from which it was probably derived."

The "stratified rocks" were separated into slates and conglomerates, although much argillite was united with the latter. The "slates" included not only the Braintree argillite, but also many of the other argillite deposits, and in common were referred to the St. John group. He further states: —

"In all the localities they are much disturbed by intrusions of igneous rock (which is sometimes poured out over them), are faulted, hardened and distorted."

Mr. Dodge considers the conglomerate as overlying the Braintree argillite, and as being probably of Carboniferous age. (Proc. Bost. Soc. Nat. Hist., 1875, XVII., pp. 411, 412.) Dr. Hunt states in the same volume that he regards the argillite about Boston Harbor as being of the same age as the Braintree argillite. (Ibid., pp. 486–488.)

The following is a quotation embodying remarks made by Dr. Hunt, at a meeting of the Boston Natural History Society, in the same year: —

"The crystalline rock, ... seen in contact with the fossiliferous Lower Cambrian (Menevian) strata of Braintree, Mass., is clearly a variety of the feldspar-porphyry or orthopyre, which is so abundant along the eastern coast of Mssachusetts, Maine and New Brunswick, and which passes on the one hand into a jaspery petrosilex, and on the other, into a finely granular, almost granitoid rock. . . . . The porphyries of Lynn, Marblehead and Salem, and the so-called jaspers of Saugus and Newbury, belong to it. This rock is identical with the porphyry which accompanies the crystalline iron ores of southeastern Missouri, and is also well displayed on the north shore of Lake Superior. It is, in all these localities, distinctly stratified, and has been by the speaker referred to the Huronian series of rocks. . . . . This porphyry, in the form of pebbles, often forms conglomerate beds in the Keweenaw or copper-bearing series of Lake Superior, as is well seen in the Calumet and Hecla, and the Boston and Albany mines.

"As regards the relations of the eruptive granites of our Eastern coast to the Braintree fossiliferous slates, Dr. Hunt remarked that the granites on Marblehead Neck, which resemble those of Cape Ann, are seen to cut the still older porphyries." (Proc. Bost. Soc. Nat. Hist., 1875, XVII., pp. 508–510.)

In 1876 Mr. T. T. Bouvé called attention to his views regarding the derivation of the felsites in the vicinity of Boston from the metamorphosis of the conglomerates. He remarked that, in 1870,

> "Professor Niles distinctly stated that he had traced in Dedham the conglomerate until it passed into porphyry. He had noticed the effects of metamorphism where dikes occurred, and he believed that many of our porphyritic rocks were formed from the conglomerate. These views I sustained by referring to my own observations, expressing myself satisfied that the porphyries of our vicinity, as well as the amygdaloids, were altered conglomerates. Dr. Hunt closed the discussion by saying he was confident that at Marblehead these rocks were not altered conglomerates. They were derived rocks, but from the primitive parent rock on which they rested. . . . . In conclusion I wish not only to re-express my belief in the derivation of these felsites from conglomerates, but to go one step further, and include among the rocks having the same origin, some at least of the underlying sienites. . . . . But I refrain from expressing more on this point, simply because my own observations in the field have been so limited, but will ask if the reputed succession of our rock deposits is not itself very suggestive.
>
> "Conglomerate.
>
> "Compact Feldspar, gradually passing into Porphyry.
>
> "Porphyry gradually passing into a rock intermediate between Porphyry and Sienite.
>
> "Rock intermediate between Porphyry and Sienite.
>
> "Sienite.
>
> "Now if this gives the true succession of our rocks, ... I ask if it be not a fair inference that the causes that led to the changes in the higher portions of the series, affected all, only to a much greater degree the lower; that the heat and aqueous menstruum that softened and partly changed some of the conglomerates of the upper portion forming the felsite conglomerate, ... and which melted the succeeding strata so as to produce first felsites without crystals, and below these the true porphyries, may not also by its greater intensity so thoroughly have melted down still lower strata of sedimentary rocks (conglomerates and slates perhaps), as to entirely resolve them into their original elements, recrystallize them and thus have formed sienites, some of which may have even subsequently played the role of eruptive rocks; for it by no means follows that because a rock has been sedimentary that it may not also have become likewise eruptive by being forced upward when in a semifluid state." (Proc. Bost. Soc. Nat. Hist., 1876, XVIII., pp. 217–220.)

Prof. Hyatt, in support of Mr. Bouvé's views, remarked in regard to the felsite of Marblehead Neck:

> "The porphyries appear to overlie the Salem syenites unconformably, and together with them are cut by at least two series of dioritic dykes. . . . . The porphyries, though varying greatly in aspect and in composition, are nevertheless but one formation, and derived from a vast conglomerate which appears in Lynn, Saugus, and Marblehead, and is reported to occur under the granites on the Beverly shore. The originally conglomerate nature of the entire deposit is inferred by extensive observations made by myself at Marblehead Neck, and by my assistant, Mr. W. O. Crosby, in Saugus, and the general identity of the purely crystalline porphyries of Lynn with those of Marblehead Neck, which are undoubtedly merely altered conglomerates. . . . . The change into the felsite is the most instructive, since here it is possible to trace the included pebble of dark colored, banded porphyry through all stages until it becomes a mere spot in the light colored matrix. During this change the pebble disappears by some process by which the structure is altered from without, the centre being the last point to lose its distinctive coloring or structure. . . . . The fact seems to me unquestionable, ... that both a felsite and a true porphyry were formed out of a conglomerate, without any perceptible change having been made in the form of the contained pebbles." (Proc. Bost. Soc. Nat. Hist., 1875–76, XVIII., pp. 220–225.)

Professor Hyatt points out that the felsite pebbles in the conglomerate are different from the felsite formed from it, and holds that through pressure or otherwise the pebbles form the thin laminæ seen in the banded felsite. The reader is referred to his very interesting description of the imaginary processes, since it is too lengthy to transcribe here. (Ibid., pp. 223, 224.)

Mr. W. O. Crosby, in his Report on the Geological Map of Massachusetts, 1876, says (pp. 7, 8, 10, 11): —

> "The Eozoic rocks of Massachusetts may to a large extent at least be divided lithologically and chronologically, into three divisions, which, stated in their order of sequence, are the Norian, the Huronian, and the Mont Alban. I weigh my words well when I describe these divisions as both lithological and chronological; for, ... I do not hesitate to affirm that the lithological characters of the divisions which have been worked out among the crystallines of this region, — the chronological and geographical distinctness of which I cannot doubt — are as unlike as the faunæ of any two successive geological formations."

This statement was in substance again affirmed in 1880. Of the Norian he writes: —

> "The rocks of this formation, though frequently stratified, seem in general to have been somewhat fluent, and usually exhibit more or less extravasation; but doubtless in some cases the metamorphic action has stopped short of this extreme term, though destroying all traces of bedding. In many places . . . .

> the entire formation seems to have been fluent, and the extravasation has been so extensive that the character of the rock changes nearly every rod. One important fact should be noted here, viz.: nowhere in this region does the Norian series appear to be cut by eruptives belonging to another formation, for all the extravasated rocks of this system may be easily referred to, or shown to be derived from, its stratified members. . . . . At Nahant we find slates, believed to be of Primordial age, resting upon the Norian diorites, which have been extravasated through the slates, producing extensive alterations. The coarse grained, readily disintegrating, exotic diorites, so extensively quarried in Medford, and also occurring in Somerville and Brookline, are, doubtless, extruded portions of this same series, which is the probable seat of many of the eruptive rocks, especially diorites, cutting the newer formations. . . . . Here is the real base of our geological column." (Report, 1876, pp. 8, 10, 11.)

We have in Mr. Crosby's work above quoted strongly formulated the principle that any dike cutting another rock is older than the rock it cuts, and is itself of distinctly recognizable age, — a perfectly logical result of Dr. Hunt's teachings. The "Norian" dikes in Medford, Somerville, and Brookline were found by Dr. Wadsworth to be diabase (Proc. Bost. Soc. Nat. Hist., 1877, XIX., pp. 217–237), and to belong to old basaltic eruptions. We must then conclude, according to this view, that all basaltic rocks, even the outflows of modern volcanoes, are derived from the Norian system, and are to be mapped and called Norian. To be sure we find such dikes cutting the Laurentian of other regions, but in this latter case they were doubtless extravasated downwards, as advocated recently by Professor Shaler (Mem. Vol. Bost. Soc. Nat. Hist., pp. 3–15). Dr. Wadsworth has also carefully studied the dikes both in the so-called Laurentian and Huronian, and can affirm their unity, both in macroscopical and microscopical characters.

Mr. Crosby divided his supposed Huronian rocks into the following series: hornblendic granite, felsite, diorite, stratified rocks, and limestone. Of the first series it was said: —

> "That these granites are mainly exotic, can scarcely be questioned, for we have seldom far to look, to find, in the form of enclosed angular fragments of clearly stratified rocks, evidence of their extravasation, and near the boundaries of the granites we usually find them cutting the adjoining rock, especially if that is stratified, in a manner incompatible with any theory that would regard them, in their present condition, as indigenous or endogenous. Nevertheless it is doubtless true, as suggested by Prof. N. S. Shaler, and later by Mr. T. T. Bouvé, that these granites have been derived from sedimentary rocks, and have simply reached the final term in the metamorphic process — igneous, or more probably, igneo-aqueous fusion." (Report, 1876, p. 14.)

Mr. Crosby also states emphatically that "this rock [the granite of Rockport] is destitute of mica, or at least its presence is a very rare occurrence." Dr. Wadsworth showed in 1878 (Proc. Bost. Soc. Nat. Hist., XIX., pp. 309–316) that this was an error, so far as it concerned at least ninety-five per cent of the rock then quarried at Rockport. It was also pointed out, that a brief inspection of the two buildings in which Mr. Crosby had for many years been working would afford evidence of the mistake, as would also an examination of the buildings on almost any street in Boston. The correctness of these statements of Dr. Wadsworth was acknowledged by Mr. Crosby in 1880 (Contributions, p. 28).

Of the felsite Mr. Crosby writes (Report on the Geological Map of Massachusetts, 1876, pp. 17–21):—

> "In general it is a structureless rock, showing no trace of bedding; but at Dungeon Rock in Lynn, it is distinctly stratified, a dense, black variety being interstratified with a crystalline dioritic variety; and going northward in Melrose, the porphyritic character gradually disappears, the felsite becomes more siliceous, and gradually becomes interstratified with quartzite and hornblende slates. The transition is so gradual that it is impossible to define the boundary between the stratified and unstratified felsites, which proves there is no break, no natural division here. In Melrose and Malden, and at other points the porphyritic felsites exhibit frequent local passages into granite and diorite. It seems probable that considerable portions of this rock have been in a more or less fluent state, this can scarcely be doubted on the west shore of Wenuchus Lake in Lynn, where the tongue of granite penetrates the felsite; and on Marblehead Neck and the neighboring islands, there is abundant evidence of the softening and extravasation of portions of the rock. Notably on Marblehead Neck, also on Red Rock in Lynn, and at the Pirate's Glen in Saugus, and, perhaps, at other points, this felsite exhibits traces of a conglomerate origin. . . . . There are in this region two principal varieties of 'banded' or laminated felsite, which differ widely in their origins; first, that in which the banding is due to a conglomerate origin, having been produced by a flattening of the pebbles of the conglomerate; . . . . and second, the much more abundant and widely distributed variety in which the banding represents the original bedding of the rock. . . . . The banding commonly results from the interlamination of thin layers of quartzose and feldspathic materials. The thickness of the laminæ usually varies from a mere line to one-sixteenth of an inch, and seldom exceeds one-eighth of an inch. That this banding really represents stratification is proved by the regularity and continuity of the bands, since a banded structure due to the flattening of the pebbles of a conglomerate would necessarily exhibit little uniformity in the thickness of the laminæ, and I find it difficult to conceive of pebbles flattened to such an extent as to produce continuous layers of uniform thickness and yards in

extent; and it is also proved by the constancy of their strike and dip. It undoubtedly becomes more crystalline, more granitic, and passes into the Quincy granite, and the granite of Dedham. It passes into fine grained granite toward the east and south. Good examples of the granitoid felsite, of small extent, occur on Lowell's Island and the north-west shore of Marblehead. . . . .

"On Marblehead Neck the breccia, which is here more properly a conglomerate, becomes at some points, especially on Lowell's Island, a coarse, gritty, feldspathic sandstone, and both the conglomerate and sandstone pass into compact felsite, the former in two distinct ways, which, although observable at several points in this region, are best exemplified here. These two modes of metamorphism are: (1) By a blending together of the pebbles and paste, whereby the outlines of the former are lost, or, when the process is not complete, can only be seen on weathered surfaces. (2) By a flattening or drawing out of the pebbles into thin lenticular laminæ, which, more or less coalescing at their edges and lying in parallel planes, produce a stratified appearance in the rock, and give rise to a laminated or banded structure closely resembling that already described, due to original sedimentation. . . . It is further shown that the massive, structureless felsites, have probably been largely derived from massive, obscurely stratified, feldspathic slates, while the normally banded felsite represents a finely and distinctly stratified slate."

Of the diorites he remarks (Report, pp. 22, 23): —

"The diorite, like the granite, varies greatly in texture and composition. . . . . In composition it has a wider range; as already stated, it passes, by an admixture of quartz, into fine-grained hornblendic granite; and it is no less prone, by losing hornblende, to pass into felsite. Fine examples of the transition between diorite and felsite may be seen in Greenwood and Stoneham. . . . . The areas colored as diorite on the map . . . . embrace a great amount of fine grained hornblendic granite. . . . . Any observer of these two rocks will agree with me that they admit of neither a lithological nor a geographical separation. As a rule they are both eruptive, and over large areas they have been extravasated through each other so extensively, and the action has been so mutual, that the complication is complete; and I have long been accustomed to speak of them as 'mixed rocks'; and I know of no term that will better express their relations, lithologically or petrologically."

Of the stratified rocks he states (*l. c.*, pp. 23–27): —

"As already stated, we find, on going northward through Melrose, the porphyritic felsite, gradually becoming less porphyritic and assuming a stratified appearance. North of Howard Street traces of stratification are common, though porphyritic felsite occurs as far north as Greenwood. North of Central Brook, in Saugus, the felsites are chiefly stratified, the bedding increasing northward, are largely quartzose, passing into quartzite, and are frequently interstratified with hornblende slate and stratified diorite. No observer, who has been over this ground, can doubt that these different rocks are stratigraphically inseparable. Along the eastern border of this area of stratified rocks, one can find beautiful examples of the passage of stratified diorite and hornblende slate into the eruptive diorite and fine grained hornblendic granite. There is nothing abrupt about these transitions, the gradation is perfect. . . . . About four miles farther northwest, in Reading, ... we find the rocks shading insensibly into eruptive diorite and granite. . . . . The large area of diorite stretching from Stoneham to Weston includes numerous small patches of stratified rocks — hornblende slate and petrosilex. . . . . They pass frequently into the enclosing rock, showing that they are mere remnants of the stratified group, which yet preserve traces of the structure once possessed by the whole mass of the rock. . . . . It thus becomes evident that this diorite, the so-called 'Salem syenite,' has, like the diorites elsewhere, resulted from the extreme metamorphism of the stratified group. . . . . I have already indicated that much of the hornblendic granite has been derived by metamorphism from felsite. . . . . I have shown that this is the probable origin of all the Huronian granites. It is demonstrated that the most, and probably all, of the felsites of this region, are now, or were originally, stratified, and may, therefore, be logically included in the stratified group. . . . . The rocks of this area consisted once, speaking generally, of stratified felsite, hornblende slate and stratified diorite only, which were then, and are even now, so related stratigraphically, and exhibit such frequent lithological transitions, as to prove them to be members of one and the same unbroken series ; and that the felsites, by metamorphism, have given rise to granite, the hornblende slates, in like manner, to fine grained hornblendic granite approaching diorite, and the stratified diorite to eruptive diorite."

Of the Huronian formation in general it is stated (*l. c.*, pp. 27–29) : —

" All the stratified rocks of this formation north and west of Boston, including besides the so-called stratified group, the dolomites and stratified felsites, dip, with few and unimportant exceptions, to the northwest. . . . . Since the limits of the different rocks are marked by gradual transitions, which precludes the existence of faults of any great extent ; and since there are no apparent repetitions of the different rocks, which precludes the existence of considerable folds of the strata ; we are forced to the conclusion that the geographical arrangement corresponds to the stratigraphical succession ; and the rocks to the south-east must underlie those to the north-west — the felsites must be older than the hornblende slates and diorites. . . . . Since the granites are more intimately associated with the felsites than any other of the stratified rocks, and are probably derived from them ; and since the exotic granites occur as eruptives through *all* the stratified rock ; the inference is plain that the granites belong normally at the bottom of the series, and may be taken to represent the lower portions of the felsite. . . . . The oneness of formation has been established ; it is proved by its petrological, its lithological, and as I have elsewhere shown its chemical characters. I have pointed out, in the preceding pages, that it distinctly *overlies* the Norian rocks ; and it no less clearly *underlies* the Mont Alban. It exhibits much greater disturbance than the Mont Alban, but less than the Norian ; and near the common boundaries of this series and the Mont Alban, the gneiss of the latter is cut by the eruptive granite and diorite of the former. And since this series so closely resembles, in its internal characters and its external relations, the Huronian of other regions, we are bound to conclude that it *is* the Huronian."

Of the argillite and conglomerate in the vicinity of Boston, Mr. Crosby remarks (*l. c.*, pp. 40–42) : —

"Although the fossils characteristic of the Acadian group have been found at only one locality in Massachusetts, viz., Hayward's quarry, in Braintree, yet most observers agree that the greater portion of the slates in the vicinity of Boston are probably of Primordial age ; and I have so represented them on the map. . . . . The conglomerate so well developed about Boston, and widely known as the Roxbury conglomerate, is lithologically identical with the carboniferous conglomerate of Bristol county and Rhode Island, and seems to be similarly related to the Primordial rocks. It has been frequently referred to the Carboniferous horizon ; and, in view of the facts just cited, and the absence of any positive evidence to the contrary, this is certainly the most probable view of its age."

Dr. Wadsworth published, in 1877, a description of the dikes in certain portions of the Boston basin, based on a study of their field relations and microscopic characters. He showed that the supposed hornblende was in general augite, and that the rocks were old basaltic ones belonging to the melaphyr and diabase varieties. It was also proved that dikes of two, if not three, distinct periods existed here, and that the later faulted the earlier ones. In 1878 he also showed that the Rockport granite was of two varieties, a micaceous and a hornblendic one. These were found by careful observation on continuous exposed surfaces to pass into one another, usually having an intermediate grade containing both hornblende and mica. (Proc. Bost. Soc. Nat. Hist., XIX., pp. 217–237, 309–316.)

In a paper "On a Possible Origin of Petrosilicious Rocks" (Proc. Bost. Soc. Nat. Hist., 1879, XX., pp. 160–169), Mr. Crosby advocated the view that the felsites were of a deep-sea origin corresponding to the "red clay" of the Challenger Expedition. In this paper he remarks : —

"These rocks, which are widely distributed over the globe and compose formations of great extent, are undoubtedly of marine origin. We can scarcely regard them as shore deposits, and therefore it seems natural and legitimate to conclude that they were formed in the deep sea ; and I would submit that

> they are very fairly represented by the modern abyssal accumulations, especially if we take into account the enormous period of time which has elapsed since their formation, and the probable changes in the physics and chemistry of the sea which it has wrought. The petrosilicious rocks are often distinctly and beautifully banded. This structure usually results from the alternation of very thin and regular quartzose and feldspathic layers, and although doubtless originating in, and determined in direction by, the sedimentary process, I think it can be proved that it has been made much sharper and more definite by a subsequent partial segregation of the ingredients, especially the Silica."

Dr. Wadsworth, from examinations of the felsites in the field and under the microscope, became convinced, in 1878, that their characters were the same, excepting in their alteration, as those of the volcanic rhyolites so common in the Cordilleras, the banding being a fluidal structure. He convinced himself that we had here the remains of ancient volcanic action, shown by ashes and other ejected fragmental material, lava flows, dikes, etc., such as at the present day accompany eruptive action. Subsequently the whole series had been more or less altered by various agencies. While in some places a recomposed conglomerate was found made up of water-worn detritus resting on the parent felsite, the structure as a whole was unlike that described by Messrs. Hyatt and Hunt.

Dr. Wadsworth found that in many cases there had first been thrown out a rhyolitic ash, and that through, around, and over this ash the rhyolitic lava has been poured, — the structure being identical with that observable in the more recent lava flows of the West. No passage could be traced between the fragmental and non-fragmental forms, but distinct lines separating the two could be found on careful observation.

Dr. Wadsworth also ascertained that two or more distinct flows had taken place at Marblehead Neck, and that the felsite also cut the granite in dikes of various dimensions. The opposite view had been taught by Messrs. Hunt and Crosby, but their evidence was taken from some felsite dikes cutting the granite near the boundaries of the main masses of these rocks, where only the most careful examination would show which was the intrusive one. Dr. Wadsworth's statement was based on finding smaller dikes of felsite, which gradually narrow and come to an end in the granite and on felsite dikes which hold fragments torn from their granite walls. He has examined the relations of the two rocks over much of the coast, and has always found the same relation between them.

As a result of microscopic investigations the banding was found to be a fluidal structure, and not due to a linear arrangement of the quartz and feldspar, as had been supposed by some. The base of the felsite has become devitrified, as is seen to have been the case, to a less extent perhaps, in many modern rhyolites. The grains and crystals in the groundmass extend from one band to another, and do not have a stratified arrangement. Dr. Wadsworth's conclusions were published in 1879, in the Bulletin of this Museum (V., pp. 275–287).

Dr. Wadsworth, not being able to find the time necessary for a thorough examination of the felsites in the vicinity of Boston, with a view to a complete elucidation of the question whether these rocks were of sedimentary or of eruptive origin, called for assistance on one of his pupils, Mr. J. S. Diller, assigning to him, as a subject for a thesis,* the felsites and the associated rocks in a district selected as being suitable for throwing light on the question at issue, and also because it was one in which Dr. Wadsworth himself had done but little work, so that the pupil would not feel in any way hampered by conclusions previously reached by his teachers. All that was asked of Mr. Diller was to observe the facts carefully, and give the conclusions to which they led, let the results be what they would.

Mr. Diller's work gradually expanded, until he took in finally almost all of the felsitic area north of Boston. He made a detailed map of the region examined, and published his results in the Proceedings of the Boston Society of Natural History; and again, when further extended, in the Bulletin of this Museum. Mr. Diller showed in the district studied by him that a series of stratified rocks occurred, which he regarded as the oldest rocks observed. These were intersected by distinctly eruptive granite, and this again by felsite. All were again cut through and through by successive eruptions of basaltic rocks.

He concludes that there is no true felsite belonging to the stratified group, the quartzite and slates being wholly distinct from the felsites both in structure and origin. It will be remembered that Mr. Crosby stated that, on going northward in Mr. Diller's district, the porphyritic character of the felsite gradually disappeared, the latter becoming interstratified with quartzite and hornblende slates. It was said that the transition was so gradual that no boundary line could be drawn between the stratified and unstratified portions, thus proving that there was no break and no natural division here.

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* Mr. Diller was at that time (1880–81) a candidate for the degree of S. B. in Harvard University. Later he was appointed Geologist to the Assos Expedition, and is now in the employ of the U. S. Geological Survey.

Mr. Diller, on the other hand, showed that the felsites were not exposed within some eight hundred and fifty feet of the stratified rocks, and that when last seen they were as porphyritic as at any other point. The accuracy of his work has not been impeached by any one ; nor is it easy to see how his conclusions can fail of acceptance on the part of those familiar with the lithological characters of eruptive rocks.

Mr. Diller found the granite breaking through and holding fragments of the stratified rocks. The felsite was seen always to cut the granite, but the reverse could not be found. Splinters in curved and crescent-shaped forms were found in the rhyolitic (felsitic) ash, and in their forms were identical with those so commonly occurring in the rhyolitic ashes of the West. These forms, as would naturally occur in such old glasses, were replaced by silicious material, forming pseudomorphs. The microscopic characters thus sustained the relations indicated by the work in the field. Mr. Diller clearly showed that, while part of the ashy material was earlier than one felsite at least, since it was cut by dikes of it, it had been in part worked over by water and stratified. This water-deposited ash passed into conglomerate and sandstone in places, as is natural in any detrital material having that origin. The ash when consolidated closely resembled the parent rock, and led many observers to think that here the transition between sedimentary rocks and true felsites occurred. (Proc. Bost. Soc. Nat. Hist., 1880, XX., pp. 355–368 ; Bull. Mus. Comp. Zoöl., 1881, VII., pp. 165–180.)

The present writers examined from time to time, in company with Mr. Diller, parts of the region he was engaged in investigating, as well as his microscopic sections, and are thus able from personal knowledge to testify to the accuracy of his work. In our opinion, there can be no doubt that the felsitic rocks of Eastern Massachusetts show all the characters that a modern volcanic rhyolitic district would, if situated on a sea-shore, and afterwards subjected to the ordinary denuding and metamorphic agencies. In places, in the field, there can be but little difference perceived between the modern and ancient forms.

In his Contributions to the Geology of Eastern Massachusetts, 1880, on account of some objections made by Dr. Hunt, Mr. Crosby called the Norian series of his former paper, the "Naugus Head series." The account of its generally eruptive character is given nearly as before, and is as follows (pp. 18–22) : —

> "That this series of pyroxenic and feldspathic rocks, with its associated minerals, — which is sometimes stratified, oftener eruptive, frequently very coarsely crystalline, and always quartzless, — is distinct from anything ob-

served elsewhere in Massachusetts, cannot be doubted. Lithologically at least it may be said to be *sui generis* in Massachusetts geology. The great disturbance which the Naugus Head series everywhere exhibits, and its thoroughly crystalline appearance, stamp it as older than the Huronian and Montalban formations. . . . . What, now, are the geognostical relations of the Naugus Head series to these Huronian terranes? It underlies them. Everywhere, along the boundaries of the Naugus Head areas, we find the various members of this series penetrating and cutting through the Huronian rocks. But the converse of this is never observed. Nowhere, so far as my observations extend, does the Naugus Head series appear to be cut by the adjoining Huronian rocks; nor by any member of the Huronian system; nor, in fact, by any rocks not easily referable, as already stated, to the stratified portions of this series itself. In short, the Naugus Head series appears to be, as it were, at the bottom; and, while it has been extravasated extensively through superjacent formations, it is penetrated by nothing foreign to itself. . . . . The Naugus Head series is certainly distinct from, and . . . . probably underlies, the Huronian; and, since it bears no likeness to the Laurentian system, we are brought to the conclusion, that, if it is to be correlated with any series already described, that series is the Norian. In short, the Naugus Head series does not resemble the Laurentian, and is, stratigraphically, where we should expect to find the Norian. . . . . The only rocks in Massachusetts that have been observed passing below the Huronian system, or cutting through its lower members, are those composing the Naugus Head series; and this, together with its crystalline character and immense disturbance, convinces me that this series is the oldest in the State. In the light of our present knowledge the conclusion cannot be avoided, that the Naugus Head series is the real base of the geological column of Massachusetts."

An examination of this so-called Norian or Naugus Head region and its rocks, by Dr. Wadsworth, has shown that the chief rock is of similar character to the zircon syenite of Norway, and that it consists principally of orthoclase, with hornblende and some microcline and plagioclase, together with microscopic and macroscopic zircons. The feldspar has the same inclusions as that of Norway. At Naugus Head a dark micaceous schistose rock occurs. Through this schist the syenite has been erupted, forming long bands parallel with the foliation. These bands vary from a fraction of an inch to many feet in thickness This structure strikingly resembles stratification, and has been taken as such; but, if a careful examination is made, it will be seen that the syenite follows the foliation only approximately, and that after running some distance it suddenly shoots across the foliation into other bands. Fragments of the schist are abundantly enclosed in the syenite, while dikes of the latter can be seen cutting directly across the schist.

At this locality, and elsewhere about the harbor, the syenite can be seen cutting irregularly through the schist in every direction, thus forming with it a network of fragments. Such also is the case with the granite along the seaward shore of Marblehead, both north and south of the Neck. The breaking of the syenite across the foliation, the interlocking of its bands, its included fragments of schist, its irregular network structure as well as its cross dikes, and the fact that, like the granite, it sometimes covers large areas alone, — all this proves that it is an eruptive rock of later date than the schist, and not interstratified with it. Furthermore, it was observed that the "Naugus Head Series" was cut both by granite and felsite, and that the statements to the contrary were incorrect. In addition to the syenite numerous dikes of diabase occur of different periods, probably separated by long intervals of time. (Proc. Bost. Soc. Nat. Hist., 1881, XXI., p. 294, Feb. 1, 1882; Harvard Univ. Bull., 1882, II., p. 359.)

Of the Huronian system Mr. Crosby remarks (Contributions, pp. 26, 27, 34, 36, 37, 38, 43, 45): —

"The Huronian system in this region, like the Naugus Head series, though in a somewhat less degree, exhibits great disturbance. Distinctly bedded rocks are the exception; and, although many apparently structureless rocks are probably really stratified, it is undoubtedly true that a large part, perhaps the greater part, of the formation has been more or less fluent, and extravasation may be set down as a characteristic structural feature. . . . . The Huronian series of Eastern Massachusetts is principally composed of the following rocks, or, rather, groups of rocks: —

1. Granite (hornblendic and binary).
2. Petrosilex (passing into felsite and quartzite).
3. Diorite (unstratified and largely exotic).
4. Hornblendic Gneiss, Stratified Diorite, etc.
5. Limestone.

"Although so connected lithologically and stratigraphically as to be clearly members of one great series, yet these various groups are, on the whole, well separated, occurring mainly in large masses. The stratigraphic distinctness would be much more striking but for the wide-spread extravasation which some of the divisions have experienced. . . . . The true sequence, excluding some of the limestone, is expressed in the foregoing classification.

"The Huronian granites of this region sometimes exhibit traces of stratification. Many examples of well-marked bedding have probably escaped observation; and there can be little doubt that the granites in some cases really possess a gneissic structure where the rock is too coarse and massive to enable the eye to detect it. Yet I do not hesitate to assert that such phenomena must, wherever occurring, be very local; for it can be proved beyond a doubt that the Huronian granites of this region are mainly exotic. We have seldom far to look to find, in the form of enclosed, angular fragments of clearly-stratified rocks, evidence of their extravasation ; and near the boundaries of the granites we often observe them cutting the adjoining rocks, especially if these are stratified, in a manner incompatible with any theory that would regard them, in their present condition, as chiefly indigenous. . . . . Believing with Prof. Shaler, and also with Mr. T. T. Bouvé, that all these granites are metamorphosed sediments, I conceive that the peculiar planes of separation (joint structure) referred to by Prof. Shaler demand a different interpretation from that proposed by him, for evidence is not wanting of the extravasation of the granite at many points along the Blue Hill or Quincy and Milton range. . . . . It is well known that the Quincy granite is met along its northern border by conglomerate and slate. . . . . The actual contact of this rock with the granite is displayed, however, at a place about ½ mile west of the Old Colony R. R. . . . . The contact line is extremely irregular ; and the relation of the granite to the semi-crystalline rock is unquestionably that of an exotic. Some three miles to the southwest, it is very distinctly cut by dykes and irregular strings of the underlying and surrounding granite. According to Prof. W. H. Niles, the relations of the granite and slate on Weymouth Fore River, near the trilobite quarry, affords equally conclusive evidence that at least a portion of the granite has experienced some extravasation since the deposition of the slate. The slates on the South Shore R. R., immediately east of the station at Weymouth Landing, are in contact with the granite, which cuts through, and overlies them in a manner possible, apparently only with an exotic ; and at the contact of the granite and slate, southwest of the station, Prof. Niles has observed angular fragments of slate actually enclosed in the granite, though lying only a few inches from their original positions in the parent bed. The induration, as if by heat, of the slate and conglomerate at most points where they adjoin the granite, and the frequent development of amygdaloidal characters in the slate in those places, are also facts which tell strongly in favor of the former igneous condition of the granite. The evidence of the extravasation of the granite afforded by a study of its relations to the uncrystalline rocks appears to be sufficiently conclusive as regards the portions of granite immediately involved. . . . . At Hospital Point on the Beverly shore, near the water's edge south of the lighthouse, is a considerable mass of distinct mica-slate enclosed in the coarse, structureless granite. A smaller mass of a similar stratified schist is enclosed in the granite near the northern end of the railroad-cut in Beverly. On Marblehead Neck the relations of the granite to the fine-grained, distinctly stratified schist occurring there, are such as to leave no doubt that the granite is exotic. Along the shore, at the southwestern end of the neck, the exposures are magnificent, and one can see, especially at low tide, numerous angular, ragged, contorted masses of the schist, of various sizes, enveloped by the granite. . . . . It has been set down by all observers as the oldest rock in this region, and this view is abundantly justified (except as regards the Naugus Head series), not only by its generally coarsely crystalline aspect and the great disturbance and almost complete absence of stratification which it everywhere exhibits, but also by the general fact that it cuts, as an exotic, all the other members of the Huronian system. In fact it pierces, in its well-nigh universal extravasation, every rock in this region, save the Naugus Head series and the newer uncrystallines. In its geographical distribution we have a strong indication that the granite belongs to the Huronian system ; for it is co-extensive with that system, and does not occur beyond its limits. And it will be shown farther on that its lithological relations point indubitably to the same conclusion. But its petrology makes it clear that, if the granite is referred to the Huronian series, it must be regarded as the lowest, and hence the oldest member of that series. It appears, in fact, to be the foundation of the Huronian system in Massachusetts. . . . . Although well satisfied that a large proportion of the granite has been in a state of igneous plasticity, yet its relations to the stratified petrosilex and the many traces of bedding which it still retains forbid me to believe that the mass of this rock has been elevated from any vast depth ; it seems rather like an extensive stratified formation which has been softened *in situ*, and then to a greater or less extent forced out of its normal position by the pressure of surrounding and overlying terranes"

Mr. Crosby now classed nearly all of the felsite under that obsolete term petrosilex, following in this, as in almost all of his work, the ideas of Dr. Hunt. Of the felsite and its relations to other rocks he says (*l. c.*, pp. 47–69) : —

"The petrosilex of this region is overlaid at many points by a group of rocks, including the well-known petrosilex breccia, which appear to be in every case merely the more or less thoroughly reconsolidated mechanical débris of petrosilex itself. This second group of petrosilicious rocks constitutes one member or division of a formation much newer than the Huronian, for which I have proposed, provisionally, the name Shawmut group : a semi-crystalline series which, as will appear in the sequel, underlies the primordial slate and conglomerate of Eastern Massachusetts, coming between these oldest Paleozoic sediments and the Huronian beds, and appearing to have been formed toward the close of Eozoic time. The petrosilicious portion of the Shawmut group includes rocks of all textures, from a coarse breccia to a compact, homogeneous rock which the naked eye cannot distinguish from the parent petrosilex. They are proved to be of more recent origin than the Huronian petrosilex, not only by their petrological relations, since they everywhere overlie the Huronian, but also and most conclusively by the fact, already stated, that they are composed mainly of the débris of petrosilex, which, where the material is coarse, can be plainly seen to be identical with that which may be referred with certainty to the Huronian system. . . . . That the Huronian petrosilex is now for the most part a stratified rock, and was originally wholly so, I cannot doubt ; and it appears most probable that the conditions presiding over its deposition differed in degree only, if at all, from those that have obtained in more recent geological times. . . . . So far as I am aware, those limited portions of the Huronian petrosilex containing distinctly marked pebbles occur chiefly in the immediate vicinity of the petrosilex breccia of the Shawmut group ; and in nearly every instance the evidence is plain that the petrosilex has experienced some extravasation, and has, consequently, been in a more or less fluent state. . . . . On the eastern shore of Marblehead Neck . . . . the former reposes directly upon the latter ; and both series have evidently suffered great disturbance. The light-colored Shawmut breccia is cut and torn in every direction by tortuous dykes of the black petrosilex, which itself very clearly holds angular pebbles of different varieties of petrosilex. . . . . The main point to be proved in this connection is brought out at this locality with especial clearness ; viz., that the very same petrosilex which holds pebbles underlies, and is in part eruptive through, the breccia, forcing the conclusion that, in spite of a certain superficial resemblance, these are distinct formations. . . . . To summarize, the facts observable at the places named, and elsewhere, compel us to suppose that the petrosilex, while suffering great disturbance, has been locally crushed and brecciated, and that certain portions of this rock, perhaps as a consequence of enormous friction, have been softened to an extent that would permit the envelopment of extraneous masses. . . . . The theory of the conglomerate origin of the banded petrosilex . . . . is I think based upon an entire misapprehension of the principal facts."

He admits the extravasation of the felsite through the brecciated material or ash, and states that the evidence that the banding was formed by flattened pebbles "is wholly illusory." (*l. c.*, p. 68.)

He claims that in Melrose is a locality that

"places beyond question the fact that there is a gradual transition between the quartzite and petrosilex, and that portions of the latter rock are intercalated in the stratified group." (*l. c.*, p. 106.)

This locality, however, was, as already mentioned, studied by Mr. Diller, and nothing of the kind found there. Dr. Wadsworth also examined the rocks in place at that locality, and found no felsite or any other rock that ought to be mistaken for a felsite.

Mr. Crosby further states : —

"The conclusion is now certainly safe that the eruptive diorites and the stratified group are unequally metamorphosed portions of one great series of basic rocks." (*l. c.*, p. 112.)

But this, like his other conclusions, rests on his inability to distinguish between different rocks, and is purely theoretical.

In 1879 Prof. N. S. Shaler took the ground that the shales and conglomerates of Roxbury passed into the amygdaloidal melaphyr, locally known as the Brighton amygdaloid. He held that a "trained eye" could trace the gradual passage from the conglomerate to the melaphyr, remarking as follows: —

> "We see . . . . a mass of conglomerate essentially the same as the Roxbury pudding stone, only the pebbles and the cement have been greatly affected by heat, so that the whole is more fused together than in the ordinary forms of that conglomerate — looking closely we see that the matrix of the pebbles and to a certain extent the outer parts of the pebbles themselves are filled with cavities in which similar amygdules have been formed. With care and with favorable conditions of the quarries, the observer may trace the stages of this transition, from the faintest beginning of this structure in rocks which are distinctly conglomerates, into rocks where the blebs have been so completely developed that every trace of the original pebbly structure is now lost, and the mass converted into the amygdaloidal trap." (Proc. Bost. Soc. Nat. Hist., 1879, XX., pp. 129–133.)

From this he argued that the Roxbury conglomerate had been deeply buried under sedimentary deposits, forming lofty mountains, which had since been worn away to their foundations, the conglomerate in the mean time undergoing fusion, and being thus converted into melaphyr.

Later, the question of the nature of the Brighton melaphyr (amygdaloid) was taken up by Prof. E. R. Benton, who showed that the amygdaloid was a melaphyr or an old altered basalt, which owed its present variation from basalt to changes subsequent to its original formation. The structure he regarded as pseudo-amygdaloid, and the supposed pebbles and fragments were shown to be the same as the remaining portion of the melaphyr. He also points to the fact that Professor Shaler's hypothesis requires the heterogeneous pebbles of the conglomerate to be transformed into the homogeneous ones of the melaphyr; also, that no part of the melaphyr is like the Roxbury conglomerate. Professor Benton further showed that all the claims made in the past, that the melaphyr passed into slates, conglomerates, etc., were without any basis of fact, for a distinct line of separation between these rocks could be found whenever they were seen together. (Proc. Bost. Soc. Nat. Hist., 1880, XX., pp. 416–426.)

Associated with the general belief in the production of crystalline and eruptive rocks by the fusion of sediments is the theory of the plasticity of pebbles in conglomerates, a theory at least as old as the days of Michael Kirwan. Certain forms observed in Brighton were regarded by Mr. Crosby as the result of the compression of the quartzite pebbles in a plastic state, but on examining the district in question Dr. Wadsworth found that these forms were confined to glaciated surfaces, and were not met with elsewhere in the conglomerate. Some of the indentations were much deeper than they were broad, and hence could not have been formed by the pressure of one rounded pebble upon another. Mr. Crosby claimed that certain fissuring in the pebbles occurred during the time of the compression; but these fissures were found to be filled with vein-crystals of quartz, which had suffered the same indentation as the pebble, so that it was impossible for both to have been formed at the same time. The forms in question were attributed by Dr. Wadsworth to glaciation, the rock being found to be smoothed on both its north and south sides as well as in its depressions; while sand action later appeared to have given rise to some of the peculiar forms observed, either directly or by the modification of previously existing surfaces. It was also pointed out by him that some pebbles had indeed been compressed and indented; but that the forms exhibited in such cases were different from the peculiar ones under discussion; the indentations, fractures, etc. being such as would naturally take place when a fragmental rock like quartzite was subjected to compression. It was furthermore remarked, that no softening and plasticity could have occurred, because the grains of quartz were round and intact, and not flattened, as Mr. Crosby's view demanded.

This subject of plasticity of the conglomerate pebbles was again under discussion before the Boston Society of Natural History, Mr. Crosby claiming that he found compressed forms below the original surface, and attempting to explain them by saying that they were due to a lack of cohesion amongst the sand grains in the quartzite. This ground had, however, been already taken by Dr. Wadsworth for certain forms observed; and it will be noticed that it begs entirely the question of the softening and plasticity claimed. A rock that has been softened by metamorphic agencies, so as to have become plastic, must be so throughout its entire mass. Mr. Crosby's view was similar to that which would be taken in regard to sand, if it were to be said that it ran through a hole by virtue of its plasticity.

Mr. Crosby also tried to show that the pebbles of the Bellingham conglomerate had been squeezed or pulled out into spindle-shaped masses; but it was evident to more than one who examined his specimens, that he had confounded the adhering matrix with the pebbles themselves, — a not uncommon mistake. (Proc. Bost. Soc. Nat. Hist., 1879–80, XX., pp. 308–318, 368–378, 405.)

Mr. W. W. Dodge gave, in 1881, a paper containing numerous details of his observations in the vicinity of Boston. In this paper he noticed the occurrence of felsite dikes in the granite, as had been previously indicated by Dr. Wadsworth and Mr. Diller. (Proc. Bost. Soc. Nat. Hist., 1881, XXI., pp. 197–216.)

In 1881 Dr. Wadsworth showed that the rock which Mr. Crosby had regarded as slate or sandstone on Marblehead Neck was really a lava flow, — a trachyte; and hence it appeared that the theory of the latter regarding the filling of Marblehead Harbor by sandstone, and its subsequent erosion, was based on an error regarding the nature of the rock in question. (Ibid., pp. 288–294.)

Dr. Wadsworth also showed that the so-called diorite or syenite of Marblehead was a diabase. (Ibid., p. 306.)

It was later pointed out that a supposed felsite on Central Avenue, Milton, from the detritus of which the associated conglomerate was believed by Mr. Crosby to have been formed, was simply a modified portion of the conglomerate itself, and that here as elsewhere the usual mistakes regarding the character of the rocks had been made. (Bull. Harv. Univ., 1882, II., pp. 431, 432.)

In a paper presented to the Boston Society of Natural History in 1883, it was pointed out by Dr. Wadsworth that the Roxbury conglomerate unconformably overlaid the argillite, and contained fragments of the latter. The argillite showed an old eroded surface, with its strata cut off; while abutting against the laminæ was the conglomerate that had been deposited on this surface. Mr. Crosby had held that the conglomerate lay beneath the argillite, and explained the appearance at the locality in question by supposing the existence of a closely folded synclinal; but the evidence that the conglomerate is really unconformably laid down on the older argillite and contains its *débris*, Dr. Wadsworth thinks, must be patent to any one who carefully examines the locality. No faulting exists, for the two rocks are so closely adherent that both can be removed as a single piece, which distinctly shows the unconformability. It was further shown that an argillite occurred interbedded with the conglomerate, and that a conglomerate of a later date than the Quincy granite had been found on the northern side of that rock. The argillite beneath the conglomerate in the Boston Basin is a fine-grained compact rock, while that associated with the conglomerate is coarse-grained arenaceous, passing into sandstone and conglomerate. To the former belong the Newton, and probably the Braintree argillites; while to the latter is provisionally referred the misnamed Cambridge slates.

In 1883 Mr. W. W. Dodge claimed that two granites existed in the Quincy district, the outer being older than the inner one, but he gave no evidence in support of this view. (Amer. Jour. Sci., 1883, (3) XXV., pp. 65–71.)

Dr. Wadsworth showed, in 1881, that the Quincy granite was intrusive in the fossiliferous argillite, and that the supposed sandstone and quartzite of Professor Shaler — the felsite (orthophyre) of Dr. Hunt — was simply the granite modified by its contact with the argillite. No faulting existed, for the two rocks were welded into a solid mass. He also pointed out that the dip of the argillite was southerly, instead of northerly, as had been claimed by Messrs. Rogers, Jackson, and Shaler. (Proc. Bost. Soc. Nat. Hist., 1881, XXI., pp. 274–277.)

VERMONT AND WESTERN MASSACHUSETTS.

The geology of Eastern Massachusetts presents us, as has been seen in the preceding pages, with a complication of problems, toward the solution of which but little progress was made by the earlier investigators. A similar condition of things is revealed when we examine what has been published in regard to the age and sequence of the formations in the western portion of the State. Of what was known on this subject at the time of the publication of President Hitchcock's Final Report on the Geology of Massachusetts (1841), a good idea may be formed from the following quotation from that work in regard to the age of the limestone of Berkshire County : —

> "According to the views which have now been suggested, it will follow, that wherever we find the limestone of Berkshire county enclosed between strata of gneiss, it must be regarded as the oldest variety of that rock, or primary limestone. Where it is interstratified with mica and talcose slate, although more recent than in gneiss, it ought still probably to be regarded as primary. But when we find it above these rocks ; . . . . then as it lies immediately beneath clay slate, it may be what is called primary, or what is called transition, according as we place clay slate on the one class or the other." (Final Report on the Geology of Massachusetts, p. 581.)

Prof. H. D. Rogers, in 1856, in his sketch of the geology of the United States, furnished for publication in Johnston's Physical Atlas, makes two periods below the "Cambrian or Older Silurian"; one, the "Azoic or Semi-Metamorphic"; the other, the "Hypozoic, or True Metamorphic." The basis on which this classification rests seems to be a purely imaginative one. As an illustration of the correctness of this statement, it may be mentioned that the Coast Ranges and the Sierra Nevada of California are placed in the Azoic by Professor Rogers. At that time nothing had been ascertained in regard to the geological age of these chains; but they are now known to be made up of rocks not older than the Carboniferous, the Coast Ranges in fact being of Cretaceous and Tertiary age, with associated eruptive and intrusive matter.

Professor Rogers states that the "Azoic sediments" were succeeded by those of Palæozoic age, "in some quarters apparently with, in some without, the interruption of a disturbance of levels." The merging of the Azoic with the Metamorphic Palæozoic under one color on the map was said to have been

> "made indispensable by the absolute impossibility of ascertaining at present the true base of the Palæozoic system, for the history of Geology forbids us to believe that research has yet detected the actual horizon of the dawn of animal and vegetable life upon our globe."

Professor Rogers, at that time, seems to have known little or nothing of what had been done toward developing the geological structure of the country, either by the Lake Superior Survey, or by that of Canada. Neither was there any other than a purely theoretical basis for his division of the rocks below the Lower Silurian or Cambrian into a "semi-metamorphic" and a "true metamorphic" system.

The work of the Canada Geological Survey on the borders of Vermont — from which in a northeastern direction the rocks become less and less difficult to decipher, because their relations are less obscured by metamorphism — could not fail, if it were well done, to be of great assistance in unravelling the intricacies of New England geology.

In 1849 the first published statement appears to have been made of the results obtained by that Survey, bearing especially on the question of the continuity through New England of the Canadian formations. This statement was made by Dr. Hunt, "of the Geological Commission of Canada," and was said to be "a brief sketch of the results obtained by Mr. Logan and his associates." It reads as follows: —

> "The facts which we have stated seem to show that the sandstones and red slates with their chromiferous chloritic bands, are identical with the dolomitic, chloritic and quartzose rocks of Sutton valley, and these with the serpentines and quartzose rocks of the valley of the Missisquoi; so that the whole of the Green Mountain rocks, including those containing the auriferous quartz veins, belong to the Hudson River group, with the possible addition of a part of the Shawangunk conglomerates. The fossiliferous rocks of the St. Francis valley

are evidently Upper Silurian and referable to the Niagara limestones; a similar formation has been met with at Gaspé and traced one hundred and fifty miles S. W.; and from the similarity of the Notre Dame to the Green Mountains and the fact that the Hudson River rocks are continuous along the St. Lawrence to Cape Rosier, we may conclude that the Upper Silurian rocks will be found continuous, or nearly so, throughout. They constitute the calcareo-micaceous formation of Prof. Adams, which he has traced nearly to the southern line of Vermont. Resting upon this formation in Gaspé is a body of arenaceous rocks, seven thousand feet thick, which apparently correspond to the Chemung and Portage group of New York, with the old red sandstones. As this formation is found extending quite to the Mississippi, it is probable that it will accompany the Silurian rocks through New England and surround the coal fields of New Brunswick, of Eastern Massachusetts and Rhode Island. To this may perhaps be referred in part the rocks of the White Mountains, which may sweep around the Western border of the Massachusetts anthracite formation until lost under the super-carboniferous rocks of the Connecticut River. The limestones of Western New England seem to be no other than the metamorphic Trenton limestones of Phillipsburg, while the chlorito-epidotic rocks and serpentines of Sutton valley appear again in the rocks of Southern Connecticut between these limestones and the new red sandstone. With such a key to the structure of the metamorphic rocks of New England and of the great Appalachian chain of which these form a part, we may regard the difficulties that have long environed the subject as in a great degree removed, and the bold conjectures as to their metamorphic origin which have been from time to time put forth, fully vindicated." (Am. Jour. Sci., 1850, (2) IX., p. 19; Proc. Am. Assoc. Adv. Sci., 1849, II., pp. 333, 334.)

In 1850 Dr. Hunt again expressed similar views with regard to the age of the Green Mountain rocks. (Proc. Am. Assoc. Adv. Sci., 1850, IV., pp. 202–204.) He declared that the view of Professor Emmons, that the Taconic system was older than the Silurian formation, was at variance with the structure of the region, as deduced both from stratigraphical and geographical analogies. After summing up the observations which, according to him, were in absolute contradiction with the theory of the pre-Silurian age of the so-called Taconic rocks, he remarks: —

> "Such are the facts that lead to the conclusion that between the crystalline rocks of the East side of Lake Champlain and the North shore of the St. Lawrence, on the one hand, and the Upper Silurian limestones at the eastern base of the Green Mountain range on the other, there are no rocks more ancient than the Silurian."

Again, in 1854, Dr. Hunt referred the crystalline limestones of Western New England, and their continuation through Northeastern New York and the adjacent parts of New Jersey and Pennsylvania, to the

Lower Silurian, citing Mather's opinion to the same effect. (Am. Jour. Sci., (2) XVIII., pp. 195–198.)

In 1861 Dr. Hunt once more stated his opinion very fully with regard to the relations of the formations of the Appalachian chain to those studied out in Canada by the Geological Survey. He closed with the following statement : —

> "It will be seen from what has been previously said that we look upon the 1st and 2d divisions described by Mr. Safford in Eastern Tennessee, as corresponding to the hypozoic series of Rogers and to the Green mountain gneissic formation, which instead of being beneath the Silurian series, is really a portion of the Quebec group more or less metamorphosed, so that we recognize nothing in New England or southeastern Canada lower than the Silurian system, nor do we at present see any evidence of older strata, such as Laurentian or Huronian, in any part of the Appalachian chain. The general conclusions which we have previously expressed with regard to the lithological, chemical and mineral relations of the Green mountain rocks remain unchanged. (This Journal [2], IX, 12)." (Am. Jour. Sci., 1861, (2) XXXI., pp. 392–414.)

In the Geology of Canada, 1863, the Green Mountains of Vermont were still regarded as belonging to the Quebec group, as above given in the preceding papers, and as being of Lower Silurian age. (See also Am. Jour. Sci., 1863, (2) XXXVI., pp. 214–226.)

In the Geology of Canada, 1866, Dr. Hunt stated : —

> "Between the Potsdam and Chazy periods, a rapid continental elevation, and subsequent gradual depression, allowed a great accumulation of deposits, which now appear in the rocks of the Green Mountain range. . . . . To this [the Upper Calciferous] succeeds the Quebec group, which is regarded as occupying a position in the series between the Calciferous and Chazy formations. The members inferior to it have not yet been observed in eastern Canada, nor, with the exception of the Potsdam of St. Albans and Georgia in Vermont . . . . The Quebec group constitutes the great metalliferous region of eastern Canada, Vermont and Newfoundland ; and the Upper Copper-bearing series of Lake Superior, in which the principal mines of that region are found, belongs to the same geological horizon." (*l. c.*, pp. 235–237.)

In 1867 Dr. Hunt said that the Quebec group formed the Appalachian region of Canada and Vermont, as well as the metalliferous terranes of Lake Superior. He then considered the Quebec group as being the equivalent of the Landeilo, and occupying a position between the Upper Calciferous and Chazy. He further remarked that this group formed the Notre-Dame Mountains in Canada, and the Green Mountains in Vermont, and that it played a very important *rôle* throughout the Appalachian chain. (Esquisse Géologique du Canada, pp. 5, 6, 12–16.)

The same year Dr. Hunt further stated that the Quebec group had been proved, stratigraphically and palæontologically, to have been deposited between the Calciferous and Chazy. Also, that this group formed that part of the Appalachian region of Canada and Vermont occupied by the Green Mountains and their prolongation to the south. (Bull. Soc. Géol. de France, 1867, (2) XXIV., pp. 666, 667.)

Again, the Taconic Mountains and the Green Mountains were said to be portions of the Lower Silurian, which had escaped erosion; while the White Mountains of New Hampshire were said to be a detached portion of the Devonian formation, the Devonian sediments having been altered to gneiss and crystalline schists. (*l. c.*, p. 687.)

In 1869 Dr. Hunt remarked: —

> "If we look at the North American continent, we find along its north-eastern portion evidence of great subsidence, and an accumulation of not less than 40,000 feet of sediment along the line of the Appalachians from the Gulf of St. Lawrence southwards, during the paleozoic period, and chiefly, it would appear, during its earlier and later portions. . . . . The region of Lake Superior, where we find the early portion of the paleozoic age marked by a great accumulation of sediments, comparable to that occurring at the same time in the region of New England, and followed or accompanied by similar plutonic phenomena." (Canadian Naturalist, 1869, (2) IV., pp. 395, 396; Smithsonian Report, 1869, p. 206.)

Still later Dr. Hunt made the following statement (Am. Jour. Sci., 1868, (2) XLVI., p. 229): —

> "To sum up in a few words — all the evidence, paleontological and stratigraphical, as yet brought forward, affords no proof of the existence in Vermont of any strata (a small spur of Laurentian excepted) lower than the Potsdam formation, which the present advocates of the Taconic system regard as forming its summit. The supposed more ancient Middle and Lower Taconic clearly consists in part of Potsdam, in part of Utica and Hudson River, and in part of the Quebec group, which also constitutes the Lower Taconic. To the upper portion of the Quebec group, the Geological Survey of Canada have already referred the gneiss of the Green mountains, assigning to this chain a synclinal structure, nor does there yet seem to be any reason to believe otherwise. That strata still older than the Potsdam of New York and Vermont were deposited in some portions of the oceanic area, is apparent from the existence in New Brunswick of the St. John's slates holding a primordial fauna older than the Potsdam, and it is not impossible that their equivalents may underlie the Potsdam of Vermont. No such rocks have, however, as yet, been detected either in Vermont or Canada, and to preserve the name of the Taconic system as the designation of a series of rocks older than the Potsdam and

lying unconformably beneath it, is simply to perpetuate an unfortunate mistake which I believe Dr. Emmons, if now living, would, with the paleontological evidence at present before the world, be the first to acknowledge."

In 1870 Dr. Hunt stated regarding the Taconic rocks in Western Vermont and Massachusetts, that "the evidence up to this time adduced with regard to these so-called Taconic rocks, has failed to show that they include any strata more ancient than the Potsdam, while most of them are certainly younger." Of the Green and White Mountains he remarks in the same paper : —

> "In fact, the schists and gneisses of the White Mountains are clearly distinct, lithologically, from the Laurentian, the Labradorian and the Huronian, as well as from the crystalline rocks of the Green Mountains, and from the fossiliferous Upper Silurian strata which lie at the southwestern base of the Canadian prolongation of the latter. Having thus exhausted the list of known sedimentary groups up to this horizon, it was evident that the crystalline strata of the White Mountains must be either (1) of Devonian age, or (2) something newer (which was highly improbable) ; or (3) must belong to a lower and hitherto unknown series." (Am. Jour. Sci., 1870, (2) L., pp. 83, 84.)

This language of Dr. Hunt, as well as other remarks in the same paper, is inexplicable, unless he still, as in the past, regarded the Green Mountain crystalline rocks as being Lower Silurian, and distinct from the Huronian.

The remarks of Dr. Hunt above quoted, beginning with the year 1863, possess an additional interest from the fact, to be shown later, that he claims that during all these years he held an entirely different opinion as regards the age of the Green Mountains, he, for official reasons, having been advocating views which he himself did not hold. It seems that later the official reasons became inoperative, for in the mean while Sir William Logan resigned his position as director of the Geological Survey of Canada, and Mr. A. R. C. Selwyn was appointed in his place.

It now appears from Dr. Hunt's various writings that some time between the date of the last quoted article, May 10, 1870, and October 19 of the same year, (he in the mean time having been appointed Professor of Geology in the Massachusetts Institute of Technology,) his views underwent a somewhat sudden "metamorphism." This showed itself in a marked manner, in 1871, in an address from which we proceed to quote, but it does not appear at first to have affected his general views of the Taconic system. The reasons for this change of opinion are nowhere given in any satisfactory manner.

In his Presidential Address before the American Association for the Advancement of Science in 1871, Dr. Hunt said:—

"The Taconic system as defined by him [Emmons] may be briefly described as a series of uncrystalline fossiliferous sediments, reposing unconformably on the crystalline schists of the Green Mountains, and partly made up of their ruins; while it is, at the same time overlaid unconformably by the Potsdam and calciferous formations of the Champlain, and constitutes the true base of the paleozoic column,—thus occupying the position of the British Cambrian. . . . . The objections made by Emmons to Rogers's view of the Champlain age of the Taconic rocks were threefold: first, the great differences in lithological characters, succession, and thickness, between these and the rocks of the Champlain division . . . . ; second, the supposed unconformable infraposition of a fossiliferous series to the Potsdam; and third, the distinct fauna which the Taconic rocks were supposed to contain. The first of these is met by the fact now established that in the Appalachian region the Champlain division is represented by rocks having, with the same organic remains, very different lithological characters, and a thickness tenfold greater than in the typical Champlain region of Northern New York. The second objection has already been answered by showing that the rocks which, as in the St. Albans section, pass beneath the Potsdam, are really newer strata belonging to the upper part of the division, and contain a characteristic fossil of the Utica slate. As to the third point, it has also been met, so far as regards the Atops and Elliptocephalus, by showing these two genera to belong to the Potsdam formation. If we inquire further into the Taconic fauna, we find that the Stockbridge limestone (the Eolian limestone of Hitchcock), which was placed by Emmons near the base of the lower Taconic (while the Olenellus slates are near the summit of the Upper Taconic), is also fossiliferous, and contains, according to the determinations of Prof. Hall, species belonging to the genera Euomphalus, Zaphrentis, Stromatopora, Chaetetes, and Stictopora. Such a fauna would lead to the conclusion that these limestones, instead of being older, were really newer than the Olenellus beds, and that the apparent order of succession was, contrary to the supposition of Emmons, the true one. This conclusion was still further confirmed by the evidence obtained in 1868 by Mr. Billings, who found in that region a great number of characteristic species of the Levis formation, many of them in beds immediately above or below the white marbles, which latter, from the recent observations of the Rev. Augustus Wing, in the vicinity of Rutland, Vermont, would seem to be among the upper beds of the Potsdam formation. Thus while some of the Taconic fossils belong to the Potsdam and Utica formations, the greater number of them, derived from beds supposed to be low down in the system, are shown to be of the age of the Levis formation. There is, therefore, at present, no evidence of the existence, among the unaltered sedimentary rocks of the western base of the Appalachians in Canada or New England, of any strata more ancient than those of the Champlain division, to which, from their organic remains, the fossiliferous Taconic rocks are shown to belong." (*l. c.*, pp. 22–24.)

Dr. Hunt further remarked in his Presidential Address : —

> "The crystalline infra-Silurian strata, to which the name of the Huronian series has been given by the Geological Survey of Canada, have sometimes been called Cambrian, from their resemblance to certain rocks in Anglesea, which have been looked upon as altered Cambrian. . . . . The Anglesea rocks are a highly inclined and much contorted series of quartzose, micaceous, chloritic, and epidotic schists, with diorites, and dark-colored chromiferous serpentines, all of which, after a careful examination of them in the collections of the Geological Survey of Great Britain, appear to me identical with the rocks of the Green Mountain, or Huronian series. . . . . The gneissic series of the Green Mountains had, however, as we have seen, been, since 1841, regarded by the brothers Rogers, Mather, Hall, Hitchcock, Adams, Logan, myself, and others, as of Silurian age. Eaton and Emmons had alone claimed for it a pre-Cambrian age, until, in 1862, Macfarlane ventured to unite it with the Huronian system, and to identify both with the crystalline schists of similar age in Norway. Later observations in Michigan justify still farther this comparison. . . . . This view [that the White Mountain rocks were Upper Silurian and Devonian] adopted and enforced by me, was farther supported by Lesley in 1860, and has been generally accepted up to this time. In 1870, however, I ventured to question it, and in a published letter, addressed to Professor Dana, concluded, from a great number of facts, that there exists a system of crystalline schists, distinct from, and newer than, the Laurentian and Huronian, to which I gave the provisional name of Terranovan, constituting the third or White Mountain series." (Proc. Am. Assoc. Adv. Sci., 1871, XX., pp. 26–28, 31, 33.)

We invite the reader's attention to the use of the term Green Mountain series as the equivalent of the Huronian, and to the statement that the White Mountain series is newer than the Huronian, hoping that he will remember it a short distance farther on.

Prof. J. D. Dana, in criticising Dr. Hunt's Address, remarked (Am. Jour. Sci., 1872, (3) III., pp. 92, 93) : —

> "That he has relied, for his chronological arrangement of the crystalline rocks of New England and elsewhere, largely on lithological evidence, and commends this style of evidence ; — when such evidence means nothing until tested by thorough stratigraphical investigation. This evidence means something, or probably so, with respect to Laurentian rocks ; but it did not until the age of the rocks, in their relations to others, was first stratigraphically ascertained. It may turn out to be worth something as regards later rocks when the facts have been carefully tested by stratigraphy. A *fossil* is proved, by careful observation, to be restricted to the rocks of a certain period before it

is used — and then cautiously — for identifying equivalent beds. Has any one *proved* by careful observation that crystals of staurolite, cyanite, or andalusite, are restricted to rocks of a certain geological period? Assumptions and opinions, however strongly emphasized, are not proofs. It is no objection to stratigraphical evidence that it is difficult to obtain; is very doubtful on account of the difficulties; may take scores of years in New England to reach any safe conclusions. It must be obtained, whatever labor and care it costs, before the real order and relations of the rocks can be known. Until then, lithology may give us guesses, but nothing more substantial. Mr. Hunt's arguments with reference to the White Mountain Series, as urged by him in 1870, will be found in this journal, II, L, 83. Both there, and in his address, may be seen the kind of evidence with which he fortifies, or supplements, that based on the character of the rocks. Direct stratigraphical investigation over the region itself, in which all flexures, faults, and unconformabilities have been thoroughly investigated, is not among the foundations of opinion which he brings forward. He endeavors to set aside the objection to his views suggested by the existence of Devonian or Helderberg rocks in central and northern New England; but he presents, for this purpose, only some general considerations, of little weight, instead of definite facts as to the extent and variety of metamorphic strata that are part of, because conformable to, these Helderberg beds. Had he studied up these stratigraphical relations with the care requisite to obtain the truth, and all the truth, perhaps he would not longer say — it is 'contrary to my notions of the geological history of the continent to suppose that rocks of Devonian age could in that region have assumed such lithological characters.' Notions often lead astray." (See also Am. Jour. Sci., 1871, (3) II., pp. 205–207; 1872, IV., pp. 104, 105.)

In replying to Professor Dana, Dr. Hunt states (Amer. Jour. Sci., 1872, (3) IV., p. 51): —

"With regard to New England rocks, Prof. Dana asserts that 'there are gneisses, mica schists, and chloritic and talcoid schists in the Taconic series.' I have, however, shown in my address that Emmons, the author of the Taconic system, expressly excluded therefrom the crystalline rocks, which he included in an older primary system; excepting, however, certain micaceous and talcose beds, which he declared to be recomposed rocks, made up from the ruins of the primary schists, and distinguished from these by the absence of the characteristic crystalline minerals which belong to the Green Mountain primary schists. Again, Prof. Dana states that I make the crystalline schists of the White Mountains a newer series than the Green Mountain rocks. A careful perusal of my address will show that I nowhere assert that the rocks of the third series, on my line of section, are younger than the second series. Such a view of their relations has, however, been maintained for the last generation by the Messrs. Rogers, Logan, and many others, all of whom assigned the crystalline schists of the White Mountains to a higher geological horizon than the Green Mountains. . . . . My 'chronological arrangement' of

New England crystalline rocks, as it is called by Professor Dana, so far as it is my own, is limited to my affirmation that they are all of pre-Cambrian age. . . . . As regards the mica-schists with staurolite, cyanite, andalusite and garnet, I have in my address pointed out the fact that they appear to belong to a great series of rocks, very constant in character, which have a continuous outcrop from the Hudson River to the St. John, a distance of 500 miles, and, in the latter region are clearly pre-Cambrian. I have, moreover, brought together the evidence of observers in other parts of North America, in Great Britain, in continental Europe, and in Australia, showing that similar crystalline schists, holding these same minerals, always occupy, in these regions, a similar geological horizon. Prof. Dana hereupon inquires whether any one has yet *proved* that these mineral characters are restricted to rocks of a certain geological period. I answer, that in opposition to these facts, it has not yet been proved that they belong to any later geological period than the one already indicated ; and that it is only by bringing together observations, as I have done, that we can ever hope to determine the geological value of these mineral fossils."

Regarding the existence of staurolite, etc., as a criterion of geological age, Dr. Hunt wrote, in 1878 : —

"It is by a misconception that some have been led to regard the presence of staurolite, cyanite and andalusite, as exclusively characteristic of the Montalban, a proposition nowhere maintained by the writer, since, although they have not been found in the oldest terranes, these mineral species have long been known to occur, in many localities, in the Taconian schists." (Azoic Rocks, p. 211.)

We do not understand what Dr. Hunt did mean, in 1872, in his remarks given above, unless he intended to hold that staurolite, cyanite, and andalusite were characteristic of Montalban schists ; neither does it seem to us that any other construction is possible. It is to be further noticed that, in his reply to Professor Dana above quoted, Dr. Hunt emphatically denied the correctness of Professor Dana's statement, that he (Hunt) made in his Address the "White Mountains (Montalban) a newer series than the Green Mountain rocks" (Huronian). It does not appear to have occurred to Professor Dana that this denial was not made in good faith by Dr. Hunt, since he (Dana) replied as follows : —

"Mr. Hunt denies that he makes, in his Address, 'the crystalline schists of the White Mountains a newer series than the Green Mountain rocks' — I had read on pages 29 and 33 of the Address approving announcements that Macfarlane had made the crystalline rocks of the Green Mountains *Huronian ;* and then, on page 34 of the Address, the statement that the White Mountain series is largely developed in Newfoundland, and that this fact had led him

(Mr. Hunt) to propose for it [the year before] the name of the *Terranovan* System. At this point in the Address there is a reference to this Journal of the preceding year, Vol. L, p. 87, 1870; and consequently by referring back to this article by Mr. Hunt, I found this Terranovan defined, Mr. Hunt saying that, according to Mr. Murray, the series comprises 'several thousand feet of strata, including soft bluish gray mica slates and micaceous limestones belonging to the *Potsdam* group, besides a great mass of whitish granitoid mica slates whose relation to the Potsdam is still uncertain.' As the Huronian is older than the Potsdam, and this equivalency of the Terranovan is not corrected in the Address, I thought I had reason for supposing that Mr. Hunt made the White Mountain series the newer. I acknowledge I prefer the view he now presents, since the less definite the statement the better as long as we have no sufficient facts for a conclusion." (Am. Jour. Sci., 1872, (3) IV., p. 105.)

Our extracts taken from Dr. Hunt's Address * show, however, that he did make the White Mountain series younger than the Green Mountain series, and that Professor Dana was correct. Furthermore, it will be shown that Dr. Hunt had advocated this view some time previous to his delivery of the Address; and that later he claimed to have advocated this order of age at the time of the Address and previously. The reader's attention is also called to the fact that in Dr. Hunt's Chemical and Geological Essays (p. 326) the sentence, "A careful perusal of my address will show that I nowhere assert that the rocks of the third series (Montalban), on my line of section, are younger than the second series" (Huronian), is expunged, although the paper purports to be a reprint of his reply to Professor Dana.

It is possible that the reader will find the reason for this expurgation in what follows. On May 1, 1871, some three and a half months before the Address was given, Dr. Hunt said:—

"In a communication to the *Boston Natural History Society* on the 19th of October last, and subsequently in the *American Journal of Science* for February and March, 1871 (pages 84 and 182), I have expressed the opinion that the porphyries . . . . are stratified rocks, belonging . . . . to the Huronian system, or Green Mountain system. . . . . I have in that same journal for July, 1870, pointed out the fact that the Eozoön of Hastings county, Ontario, occurs in a series of crystalline schists which I consider newer than the Huronian, and the equivalent of the White Mountain gneisses and mica schists." (Bull. Essex Institute, 1871, III., pp. 53, 54.)

Dr. Hunt's remarks, published in the Proceedings of the Boston Society of Natural History to which he above refers, are as follows:—

"I regard these two types of rocks (quartzo-feldspathic rocks and dioritic and chloritic rocks) as forming parts of one ancient crystalline series, which is largely developed in the vicinity of Boston, and may be traced at intervals from Newport to the Bay of Fundy, and beyond. To this same series I refer the great range of gneissic and dioritic rocks with serpentines, chloritic, talcose and epidotic schists which stretches through western New England." (*l. c.*, October 19, 1870, XIV., p. 46.)

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* See *ante*, p. 447.

The references to the American Journal are to a paper stated to have been read before the American Association, August 20, 1870, a year before the Presidential Address, and which was published in the Canadian Naturalist some eight months before that address was delivered.

He says, in the first reference to the rocks above referred to in the Proceedings of the Boston Society : —

"They apparently belong . . . . to the great Huronian series." (Am. Jour. Sci., February, 1871, (3) I., p. 84.)

The second reference reads as follows : —

"The rocks of this White Mountain series are, in the present state of our knowledge, supposed to be newer than the Huronian system . . . ., to which, with Macfarlane and Credner, I refer the crystalline schists with associated serpentines and diorites of the Green Mountains." (Am. Jour. Sci., 1871 (3) I., p. 182 ; Chemical Essays, p. 194 ; Canadian Naturalist, 1870, (2) V., p. 396.)

In Dr. Hunt's Azoic Rocks (pp. 222–224) is given part of a letter to Major T. B. Brooks, under date of February 22, 1871, nearly five months before the Indianapolis address. Since this letter is given in full in the Geology of Wisconsin, Vol. III., 1879, pp. 657–660, we prefer to take our extracts from that : —

"You remark about the *mica-schists* as being supposed by me wanting in the Huronian of Canada, and you send me Nos. 1215, 1154, 1152, 1153. Now I have for some time past recognized a *mica-schist series* which I supposed to overlie the Huronian, in fact the *White Mountain series*, provisionally named by me Terranovan [and since called Montalban]. See Am. Jour., July, 1870. I was therefore delighted to find in the specimens named well-characterized White Mountain mica-schists, holding garnets and well defined crystals of Staurolite [1153]; while the peculiarly knotted mica schist is not less characteristic. These rocks are abundantly spread to the north of Lake Superior, as last year's collection show me ; but although I have not there been able to fix their relation to the Huronian diorites, talcose schists, iron ores, etc., I conclude, from the facts seen near Portland in Maine, and those described by Rogers in Penn., they are overlying rocks, and in some cases at least unconformably so. You say that 'they are the youngest rocks in the region

> belonging to the Huronian.' I suspect that they belong to the same series. I distinguish three crystalline gneissic series : I. Laurentian (not to speak for the present of the Labrador), II. Huronian, III. Terranovan [Montalban] ; these being respectively in the United States, the rocks of the Adirondacks, the Green Mountains and the White Mountains. I hope you will be able to decide whether there is any want of conformity between II and III in your region. I should mention that in Hastings Co., Ontario, the three series all are represented, and that there is apparently a stratigraphical break between each. . . . . As regards series II, which was in 1862 declared by Macfarlane to be the same with the Green Mt. group, I have for some time been of that opinion, and have briefly expressed it in a paper on the rocks of E. Mass., read last October to the Bost. Nat. Hist. Soc. (not yet published), which compares the dioritic, chloritic and hornblendic rocks of the two series. Their copper, nickel and iron ores are characters in common. My opportunities for studying the Huronian had been very imperfect, as Mr. Murray's collections were so, and were made many years ago, and since remain, with few exceptions, packed away. It was not, therefore, till I saw the Huronian rocks displayed along the coast of New Brunswick, that I realized how much they were like the Green Mt. rocks, all of the types of which may be found on the Bay of Fundy from Eastport to the head of the bay. . . . . I have thus, I think, touched on the principal points of interest in your collection, of which the two great facts are the close resemblance, and I believe the identity, of the great *iron-bearing dioritic-talcose series*, with Green Mt. series II, and the equally close resemblance of the rocks, 1215, 1151 to 1154, with the White Mt. series III, which I conceive to belong to a higher horizon (see on this a note to my paper on granitic rocks, 2d part, Am. Jour. Sci. for March)."

While in the above letter it is written : "You say 'that they are the youngest rocks in the region belonging to the Huronian.' I suspect that they belong to the same series," — in the "Azoic Rocks," it reads : "You say that they are *the youngest rocks in the region belonging to the Huronian.* I suspect that they belong to *a younger* series." (*l. c.*, p. 223.)

Another letter by Dr. Hunt of the date of May 20, 1878 (Geology of Wisconsin, III., 1879, p. 660), contains the following : —

> "The announcements made in my letter to you identifying the formations XIX and XX (the micaceous schists, with hornblendic and staurolitic schists and the white feldspathic gneisses) with the Montalban, which I at that time (1871) ventured to declare to belong to a newer and distinct series from the Huronian, were, as you know, an anticipation of some years of the published conclusions of yours that they are the *youngest Huronian rocks*, a strong confirmation of the great value of the distinctions, which in my letter to you of February 22, 1871, were presented *for the first time*. All my subsequent work in Pennsylvania (Proc. Amer. Assoc. 1876) and in North Carolina, as well as

Fontane's work in Virginia, have confirmed this. I count this a great point gained in American stratigraphy — the recognition of the *newer gneissic series* above the Huronian, to which I have given the name of *Montalban*. (The *Terranovan* suggested in 1870, was made up of *Montalban* and Taconian, as I have since shown.)"

Later, in the Azoic Rocks (pp. 224, 225), Dr. Hunt, in referring to the first letter given above, says: —

> "The above conclusions as to this overlying gneiss and mica-schist series, was soon after made known by the writer, in his address in August, 1871, where it was said that the schists both of the Green Mountain and the White Mountain series 'are represented in Michigan, as appears by the recent collections of Major Brooks. . . . . He informs me that these latter schists are the highest of the crystalline strata in the northern peninsula. . . . . It was these schists, and the granitoid gneisses, from the Marquette region, which the writer [Dr. Hunt] so long ago as 1871, referred to the White Mountain or Montalban series, then, as now, placed by him above the Huronian — a testimony to the value of lithological characters in geology."

We thus see that Dr. Hunt had for over eighteen months advocated the view which he so emphatically denied having held; and furthermore, that after the delivery of his Presidential Address he claimed to have held it at that time. Also, we have shown that he distinctly stated the same view in that Address. But it is unnecessary for us to comment on the methods of Dr. Hunt as revealed in the preceding extracts; they speak loudly for themselves.

Professor Dana, in reference to Dr. Hunt's views regarding the age of rocks carrying crystals of staurolite, cyanite, or andalusite, remarked as follows: —

> "Now the fact is that those same Taconic rocks, unquestionably of the Taconic system according to Emmons himself, and, therefore, Hunt attesting, of Lower Silurian age, contain in some places staurolite crystals." (Am. Jour. Sci., 1872, (3) IV., pp. 104, 105.)

Also, in the same paper, Professor Dana thus replied to Dr. Hunt's remark, that Emmons expressly excluded from the Taconic system all crystalline rocks: —

> "This exclusion is an easy feat for a speculator with pen in hand, like many closet feats; but it is more than herculean in actual fact, since the very Taconic mountains themselves, that is, the very rocks called Taconic by Emmons, are partly gneiss, gneissoid mica schist, and chloritic talcoid schist, as well as talcoid schist; and these rocks are so involved together that speculation will never bring them into that kind of order which Mr. Hunt's notions require." (*l. c.*, p. 104.)

In a criticism on the Chemical and Geological Essays of Dr. Hunt, Professor Dana further states (Am. Jour. Sci., 1875, (3) IX., pp. 102, 103): —

"The reader of the volume will observe that in the Third Chapter the White Mountain series and Green Mountain series of rocks are made (as had been done by other geologists) Lower Silurian, and Upper Silurian and Devonian, in age, while in the Thirteenth Chapter (as also mentioned in the preface to Chapter III) both are pronounced pre-Silurian. In this, the older view, as I believe I have proved, is the one sustained by the facts. The new view is wholly speculative, being based on no careful stratigraphical study of the regions, but mainly upon the assumption that certain kinds of crystalline rocks are a test of geological age the world over. Since the first announcement of this doctrine by Mr. Hunt, I have spent many months in the study of the Green Mountain rocks and those of some other parts of New England, in order to ascertain whether there is any virtue in the criterion; and I have found none. Mr. Hunt makes staurolite evidence of pre-Silurian age; while, as I have shown, its crystals occur in crystalline rocks of New England that are not older than Upper Silurian. Such erroneous conclusions make it apparent that in reading the work the judgment should be held in reserve until the other side is heard. There is also another more serious reason for this reserve. For the volume contains a series of misrepresentations of the views of others wholly unnecessary to the presentation of the author's opinions, and difficult to find excuse for."

Professor Dana, in 1873, after discussing the observations of himself and others, remarks: —

"From the facts which have been presented it follows that all old-looking Green Mountain gneisses are not præ-silurian, and, further, that the presence of staurolite is no evidence of a præ-silurian age. . . . . It is not easy to avoid the conclusion that *the Taconic slates are Hudson river slates.* . . . . The Trenton limestone and Hudson River or Cincinnati groups, which properly constitute one series in American Geological History, are then *the true Taconic system.*" (Proc. Am. Assoc. Adv. Sci., 1873, XXII., B., pp. 25–29; American Naturalist, 1873, VII., pp. 658–660).

Professor Dana, in giving an account of an examination of the Helderberg rocks in the valley of the Connecticut (Am. Jour. Sci., 1873, (3) VI., p. 348), concludes that staurolite and andalusite occur in metamorphic rocks of any age, remarking that

"this Helderberg series in Central New England comprises a large part of the common kinds of metamorphic rocks, gneiss of several varieties, undistinguishable lithologically from the oldest; hornblende rock and schist; syenite gneiss; coarse mica schist and mica slate; staurolitic slate.

"A large part of the rocks that have been distinguished as of the 'Montlban' or 'White Mountain series' in New Hampshire, and regarded of pre-Silurian age, are here included, and are hence nothing but altered Helderberg sediments. It is hence far from true that 'the crystalline rocks of the Green Mountain and White Mountain series' and 'the whole of our crystalline schists of Eastern North America are not only pre-Silurian, but pre-Cambrian in age.'"

In the same article (p. 341) Professor Dana further remarks : —

> "Lithological evidence of a geological age among metamorphic rocks *of distant regions* is in general worse than worthless. It is easy to use, and presses itself on the mind most insinuatingly when a conclusion is eagerly wanted. . . . . I have further found that the Earth did not finish up its metamorphic work in pre-Silurian time, or even by the epoch closing the Primordial, as it did not its mountain-making."

For the field evidence upon which Professor Dana founded his conclusions, the reader is referred to the original article.

In the Report of Progress of the Canada Geological Survey, for the year 1873–74, Mr. Selwyn remarks that considerable doubt and uncertainty have been thrown upon the labors of Sir William Logan by articles from the pen of Dr. Hunt. These articles appear to the present head of the Canada Survey to indicate that the earlier views of Dr. Hunt in regard to the true stratigraphical positions of the rocks in Eastern Canada had undergone an almost entire revolution. This change of opinion is said by Mr. Selwyn to have been based, so far as he could understand it, on lithological comparisons exclusively, and he thus expresses his views in regard to that kind of evidence : —

> "Whether the relative ages of great masses of crumpled and metamorphic strata can be thus determined apart from, or in the absence of palæontological and stratigraphical evidence, is a question which, as a stratigraphist of thirty years' experience, I should decidedly answer in the negative. The degree and character of the metamorphism and mineralization which a group of strata exhibit, cannot be relied on as certainly indicative of geological antiquity, and, as tending to strengthen this opinion, the recent researches of Mr. Richardson in British Columbia have shown that epidotic, chloritic and serpentinous rocks, with crystalline limestones and magnetites, are as characteristic of upper palæozoic, and perhaps also of even later formations when they have been subjected to an equal amount of plication and folding, as they are of the oldest palæozoic and protozoic strata, such as those of Eastern Canada and the New England States."

In 1875 Prof. J. P. Lesley stated that in Pennsylvania the Huronian or Green Mountain series was seen to overlie the White Mountain series; while he unqualifiedly placed both series in Vermont and New Hampshire below the Potsdam. (Second Geological Survey of Pennsylvania, D., pp. 65, 66.)

Professor Dana, in a review of Professor Lesley's remarks, says (Am. Jour. Sci., 1876, (3) XI., pp. 63, 64): —

"Mr. Lesley goes outside of his field in his closing remarks, and states — what is sustained as yet by no adequate stratigraphical evidence — that the 'Green Mountain system of Vermont' and the 'White Mountain system of New Hampshire,' are, like 'the Laurentian Mountains of Canada,' older than the Potsdam; and that the Green Mountain system, one of these 'three great mountain systems of the north,' is Huronian. The observations by Mr. Prime in Pennsylvania, above mentioned, and the parallel facts in the Green Mountain system to which he draws attention, all point as regards the Green Mountains in the opposite direction. The writer has studied stratigraphically the Green Mountain region from Connecticut to Vermont, and has found that the hydro-mica and chloritic hydro-mica slates associated with the limonite beds of Berkshire are of the same formation with the hydro-mica, chloritic, and micaceous slates of Graylock and the Taconic range; and with the hydro-mica slates of the ridge lying northeast of Rutland in Vermont, and of others west and north of Rutland; and with the staurolitic schists of the limonite region of Salisbury, Connecticut. Since the limestones associated with the slates of West Rutland abound in distinct Lower Silurian fossils, referred to the Chazy by Billings, part of the Green Mountain slates and schists are unquestionably Lower Silurian. What is the age of the rest is not yet positively known."

In 1878 Professor Dana remarks: —

"Professor Lesley stated in his letter * that the opinions which he had derived, from the observations of others, more than thirty years since with regard to New England geology, he now (since the discovery of fossils in limestones among the metamorphic rocks of Vermont, of Bernardston and Littleton in the Connecticut Valley, and of Eastern Pennsylvania) regards as greatly strengthened in probability — namely: That Paleozoic rocks make up the Green Mountains, and also the White Mountains, and that the latter include beds of Devonian age." (Am. Jour. Sci., 1878, (3) XV., p. 261.)

This then is a virtual retraction by Professor Lesley of his statement in 1875 (given before), that the Green and White Mountains were pre-Potsdam in age.

Professor Dana made the following statement as the result of an extended series of observations † by himself and Rev. Augustus

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* A letter to Professor Dana, giving an account of the discovery by Mr. Prime of Lower Silurian fossils associated with mica slates in Eastern Pennsylvania.

† For Professor Dana's various papers on this subject, see Am. Jour. Sci., 1872, (3) III., pp. 179–186, 250–256; IV., pp. 133, 362–370, 450–453; V., pp. 47–53, 84–91; VI., pp. 257–279; 1877, XIII., pp. 332–347, 405–419; XIV., pp. 36–48, 132–140, 202–207, 257–264; 1879, XVII., pp. 375–388; XVIII., 61–64; 1880, XIX., pp. 191–200. See also Dwight, Am. Jour. Sci., XVII., pp. 389–392; 1880, XIX., pp. 50–54.

Wing (Am. Jour. Sci., 1877, (3) XIV., pp. 202, 203; 1879, XVII., p. 387): —

> "From the facts brought forward it is manifest that the limestone schists and quartzyte, making up the limestone series of Vermont and Berkshire, are *continuous* formations, and that they are *conformable* throughout. . . . . The limestone series is *made up wholly of Lower Silurian formations;* that is, of formations not older than the primordial or Cambrian, nor newer than the Cincinnati or Hudson River group. . . . . The Taconic mountains of western Berkshire are a direct continuation of the 'great central slate-belt' of Vermont. The two make one range and one rock-formation, and consist of the same kinds of rocks similarly upturned. . . . . In Vermont the Taconic slates (those of the central slate-belt) *overlie* the adjoining limestone in one or more synclinals, as plainly shown in Mount Dorset, Danby Mountain, Equinox Mountain, Spruce Peak in Arlington, and Mount Anthony in Bennington; and in Berkshire they have the same position, as observed in Greylock and Mount Washington. Hence in both States the *Taconic slates overlie, or are younger than, the adjoining limestone.* . . . . The Taconic schists are, according to the evidence, of the age of the Hudson River group."

The limestones and micaceous quartzites of Berkshire County, Mass., and elsewhere in New England, were stated by Dr. Hunt, in 1875, to belong to the White Mountain or Montalban series. (Proc. Bost. Soc. Nat. Hist., 1875, XVII., p. 509.)

In 1878 Dr. Hunt remarked (Preface, Chemical Essays, 2d ed., pp. xix.–xxii.) that the result of his study of the Taconic rocks had led him

> "to conclude that what has been said of them in Essay XIII. Part 1, and in Essay XV. Part 3, is only true of that portion which Emmons at first included in the upper part of his Taconic system under the general name of the Taconic slates, but in 1855 separated from the underlying portions, and described as the Upper Taconic series. This is no other than the Quebec group of Logan, which is the northward prolongation of the Taconic slates from eastern New York. . . . . The strata of this region, and of its extension north and south, including the western border of the whole Atlantic belt, from the gulf of St. Lawrence to Alabama, have, as is well known, a general high dip to the eastward, attended with many dislocations, folds, and inversions; as a result of which the newer sediments appear to pass beneath the older ones, and even beneath the still more ancient crystalline rocks of the belt, giving rise to some of the most perplexing problems in American geology. The fauna of the Upper Taconic rocks, including the forms found at Troy, New York, at Georgia, Vermont, and at Phillipsburg, Point Levis, and Bic, in the province of Quebec, presents, as far as known, nothing lower than the Menevian horizon, and belongs to the Lower and Middle Cambrian of Sedgwick. . . . . The lower Taconic series of Emmons, embracing in ascend-

ing order (1) granular quartz rock, (2) the Stockbridge limestone with its interstratified and overlying micaceous schists, and (3) argillites, including roofing slates, constitutes a distinct geological horizon of rocks essentially crystalline, having an aggregate thickness of about five thousand feet. These are found resting alike on Laurentian, Huronian, and Montalban strata, and are overlaid, probably unconformably, by the Cambrian (Upper Taconic). . . . . They are apparently identical with the great limestone series which, in Hastings county, Ontario, underlies unconformably the Trenton group of limestones, and near St. John, New Brunswick, is beneath the Menevian slates."

During the same year the Taconian series was said by Dr. Hunt to include the statuary marbles of North America, and to be overlain "by the Upper Taconic, which is identical with the Quebec Group of Logan." (Nature, 1878, XVIII., p. 444; Geol. Mag., 1878, (2) V., p. 471.)

In 1879, Dr. Hunt gives us to understand that in 1863, when he referred the Green Mountain rocks to the Quebec Group, in the "Geology of Canada," he then regarded them as Huronian, but that "*official reasons then, and for some years after, prevented the writer from expressing any dissent from the views of the director of the geological survey of Canada.*" (Proc. Am. Assoc. Adv. Sci., 1879, XXVIII., p. 285; Am. Jour. Sci., 1880, (3) XIX., p. 273.)

It would seem from the remarks we have quoted from his papers* that the "official reasons" not only prevented his dissenting from Sir William Logan's views, but also caused him to affirm their correctness in the strongest possible manner. And in connection with this statement of Dr. Hunt's, it will be well to refer to one which follows, made by him in 1871: —

> "My opportunities for studying the Huronian had been very imperfect. . . . . It was not, therefore, till I saw the Huronian rocks displayed along the coast of New Brunswick (1869–70), that I realized how much they were like the Green Mt. rocks." (Geol. of Wisc., 1880, III., p. 658.)

How again does Dr. Hunt's statement made in 1879 agree with that of 1875, in which reference is made to a paper read in 1863 advocating the palæozoic age of the rocks of the Green and White Mountains? The statement made in 1875 reads as follows: —

> "My own extended studies of these rocks in the Green Mountains, in New Brunswick, and on Lakes Superior and Huron, have *since* convinced me that this view is correct, and that the Green Mountain series is represented in the crystalline strata around the great lakes just mentioned; and, moreover, that

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* See *ante*, pp. 441–445.

both this series and the crystalline rocks of the fourth or White Mountain series existed in their present crystalline form before the deposition of the eldest Cambrian sediments."* (Chem. and Geol. Essays, p. 18.)

The following statement, made by Dr. Hunt in 1873, contains his own acknowledgment that he maintained, until 1870, views he would now have us understand he had not believed in since 1863.

"The question of the structure and origin of the Appalachians has been complicated by the assumption that the crystalline strata which constitute their higher portions are altered sediments of paleozoic age, rather than parts of an ancient continent of eozoic rocks which formed the eastern border of the paleozoic sea, corresponding to the Rocky Mountains on the west. The former view has been very generally held by American geologists, and was maintained by the present writer until 1870, when he endeavored to show that the crystalline rocks of New England and their lithological representatives both to the southwest and the northwest are of pre-paleozoic age and in part Laurentian. [This Journal, II. L, 83 . . . .]." (Am. Jour. Sci., 1873, (3) V., pp. 267, 268.)

The question arises, whether the geologist, who is desirous of finding out what Dr. Hunt's real views on any subject may be at the present time, or may have been at any time in the past, can feel any confidence that he is likely to arrive at a satisfactory result. At all events, it has been shown above that official or other conditions may be to Dr. Hunt a sufficient reason, not only for withholding his own views, but for strongly advocating that in which he himself has no belief.

In 1880 Professor Dana held that the Green Mountains were formed at the close of the Lower Silurian, and sums up the evidence on this point as follows (Am. Jour. Sci., 1880, (3) XIX., p. 200) :—

"1. The *western* half of the region between the Connecticut River valley and the Hudson River, that is, the western half of the Green Mountain area, is proved to consist of rocks that are (1) of Lower Silurian age and (2) of one orological system.

"2. The schistose rocks of the eastern half in Vermont are to a large exten similar to those of the western.

"3. The rocks of the central mountain section in Vermont are, in its northern part, identical schists (hydromica, etc.), with those on the east and west sides of it.

"4. The western border of the region in the Hudson River valley has its folded or upturned Hudson River (Lower Silurian) slates, overlaid unconformably by Niagara and Lower Helderberg (Upper Silurian) beds.

"The eastern border of the region in the Connecticut valley at Bernardston, in Massachusetts, Vernon in Vermont, and the adjoining part of New Hampshire, has lower Helderberg beds overlying, unconformably, folded or upturned roofing slates (similar to those on the western side), the Lower Silurian age of which is not improbable ; and at Littleton in New Hampshire, and on Lake Memphremagog, in northern Vermont, occur unconformable Upper Helderberg (Lower Devonian) beds with fossils. . . . . In view of these various considerations, the evidence, although not yet beyond question, is manifestly strong for embracing the whole region between the Connecticut and the Hudson (and to an unascertained distance beyond) within the limits of the Green Mountain synclinorium."

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* The italics are ours.

Professor Dana makes this statement in reference to a letter sent him by Prof. C. H. Hitchcock (Am. Jour. Sci., 1880, (3) XIX., p. 237) : —

"Prof. Hitchcock also says, in the recent letter to me, after remarking on his disbelief in 'Taconism': 'Within the past two years I have gone over most of the Vermont sections, and have felt that they demonstrated the essential equivalence of the Taconic system with the Potsdam and the overlying limestones and slates [of the Lower Silurian]. I have been throughout in essential accord with you and Mr. Wing.' He adds that Mr. Wing's views had been his for years."

Professor Hitchcock is further quoted as saying regarding the Report on the Geology of Vermont (1861), "There is nothing in the Report anywhere favorable to 'Taconism.' "

In 1877 Professor Hitchcock gave his ideas of the Green Mountain or Quebec rocks as follows : —

"Sir W. E. Logan has described them under the general name of Quebec group. . . . . He has grouped together a large series of fossiliferous Cambrian and metamorphic rocks, assuming that the one was the equivalent of the other. I have endeavored to separate the fossiliferous from the metamorphic portions, with the assistance of Dr. T. Sterry Hunt. . . . . From this series, as proposed by Logan, we must eliminate all the fossiliferous portions and invert the order. . . . . This is in agreement with the recently quoted view of Mr. Macfarlane, and has been also insisted upon by Dr. Hunt. Separating the eastern part of the area called Quebec group by Logan, we may clearly understand it to be older than the fossiliferous Cambrian of any part of the world, and therefore to be named Huronian. . . . . The Vermont Huronian, save that along Connecticut river, is the southward continuation of the Quebec group of Canada. It is divided into two parts by the central ridge of the Green Mountains, which continues a few miles into Canada. Macfarlane follows the report on the geology of Vermont in regarding the Green Mountain ranges as older than the adjacent Upper Huronian. We have in that early publication (1861) insisted that these Green Mountain rocks underlaid the green schists upon both sides, ... and they are consequently older. The name Green Mountain gneiss, as applicable to this formation, was in use in

1846; and therefore the use of the same geographical designation by Dr. Hunt, in 1871, for the Huronian, is both inappropriate and improper, on account of prior usage. The Green Mountains are not Huronian at all, though flanked by it upon both sides in the northern half of Vermont. They belong to the Montalban series. Adopting the principle of inversion, as applied to the members of the Quebec group, we find they overlie these Montalban gneisses in the proper order of succession. As Macfarlan says, those who once accepted the theory of the metamorphism of New England seem to retain erroneous notions of the age of the successive mountain ranges, calling the Green Mountains newer than the Adirondacks, and the White more recent than the Green. They are both nearer the Laurentian than the Huronian, in respect to age." (Geol. of N. H., 1877, II., pp. 463, 464; see also pp. 10, 11, 25–27, 31.)

In 1875 he said: —

"His observations led him to believe that Emmons understood the stratigraphical relations of these rocks (many of them called Taconic by him) better than most of his contemporaries." (See Proc. Bost. Soc. Nat. Hist., 1875, XVIII., pp. 191–193.)

Professor Dana in a series of papers bearing the title of "On the Geological Relations of the Limestone Belts of Westchester County, New York," (Am. Jour. Sci., 1880, (3) XX., pp. 21–32, 194–220, 359–375, 450–456; 1881, XXI., pp. 425–443; XXII., pp. 103–119,) has brought together the evidence bearing on the question of the geological age of the Green Mountain limestones and associated rocks. He remarks as follows: —

"As the fossils of the limestone had been discovered only in Vermont, it was required, in order to extend the conclusions to the rest of the Green Mountain region, that the Vermont limestone should be proved to be the same stratigraphically with that of the region to the south, and this was done by ascertaining (1) the essential continuity of the limestone from the north to the south and south-southwest; and (2) its association with similar rocks from north to south, under similar stratigraphical relations; and finally (3), by the discovery of Lower Silurian fossils in the part of these belts of limestone that reach into and beyond Dutchess County, and also in the associated Taconic schists of that County. By these means, it has been shown that the schists of the Taconic range, the limestone belts on either side, and various conformable schistose rocks and limestone belts farther east and west, are comprised within the Lower Silurian formation, and that the whole series was displaced together in the upturning and metamorphism by which the Green Mountains were made." (Am. Jour. Sci., 1880, (3) XX., p. 22.)

Professor Dana comes to the conclusion, that the limestone of Westchester County and New York Island, and the conformably associated metamorphic rocks, are of Lower Silurian age; also, that the limestone and the conformably associated rocks of the Green Mountain region, from Vermont to New York Island, are of the same age. He remarks furthermore: —

> "These Westchester County rocks have been pronounced *Montalban.* I know of no facts sustaining such a conclusion. If true, it would follow, from the above, that the original Montalban rocks — those of the White Mountains — also are Lower Silurian." (Am. Jour. Sci., 1880, (3) XX., p. 455.)

Of the correctness of these statements in regard to the Lower Silurian age of the rocks in question. it seems to us that there can be no possible doubt.

NEW YORK.

The mass of the Adirondack Mountains is composed, in large part, of highly crystalline rocks, among which that called "hypersthene rock" by Professor Emmons is the most conspicuous and important, forming as it does the highest portion of the chain, and covering, according to the same authority, the whole of Essex County. Gneiss, granite, and syenite are also present over areas of some extent, while mica schist and talc schist are said to be entirely wanting. The extent and importance of the masses or beds of magnetic and specular oxides of iron are also well known. In Professor Emmons's classification of the Adirondack formation, gneiss and syenite are put down as being stratified, while the limestone is considered as being unquestionably of eruptive origin.

The Adirondack area is admitted by geologists — without exception, it is believed — to be Azoic, or Archæan. In view of what has been stated in the preceding pages with regard to the facility with which the Azoic rocks of other regions in this county have been assigned to be Laurentian, Huronian, or Montalban, or moved backwards and forwards between these three supposed systems to suit the fancy of the theorist, it seems rather remarkable that the rocks of Northern New York should have been so little meddled with in this way. Our knowledge of the geology of the Adirondack region is so exceedingly incomplete, that a fine field lies ready there for theoretical speculations of a kind similar to those which we have shown to have been so prevalent in regard to the rocks of New England. A brief statement will here be given of what has been published bearing on the question of the division of the Adirondack rocks into two or more systems, first calling the reader's attention, however, to the fact that no one of the theoretical views advanced has been supported by sufficient evidence to make its adoption a necessity.

In 1864, Messrs. Hall and Logan announced, in a paper read before the Natural History Society of Montreal, (Canadian Naturalist, 1864, (2) I., pp. 368, 369; Am. Jour. Sci., 1865, (2) XXXIX., pp. 96, 97,) that the gneiss of the New York Highlands "presented all the aspects and characteristics of that of the Laurentian system, as seen in Northern New York and in Canada." Here it is assumed, as a matter of course, that the Adirondack region is Laurentian.

Nothing further appears to have been done until Mr. A. M. Edwards announced, in 1870, the discovery of *Eozoön Canadense* in serpentinous marble from Warren County, N. Y., this indicating, according to him, the Laurentian age of that rock. (Proc. Lyceum Nat. Hist. New York, 1870, pp. 96–98.)

Later, in 1876, Professor James Hall, in a paper entitled "Note upon the Geological Position of the Serpentine Limestone of Northern New York, and an Inquiry regarding the Relations of this Limestone to the Eozoon Limestones of Canada," (Am. Jour. Sci., 1876, (3) XII., pp. 298–300,) remarked of the Azoic area in question that the formations occupying that space, "originally called Primary, and afterwards Laurentian," were now known to "represent several geological periods." No proof of this is furnished; but it is further stated that there is a lower division of the Laurentian, "succeeded by massive beds of labradorite rock and other granite rocks." The lower division is said to consist of black hornblendic, gray garnetiferous, and coarse feldspathic and quartzose gneisses, with extensive beds of magnetic iron ore. The succession between this lower series and the upper one is said to be unconformable. In regard to this unconformability it is further stated that "the interval between the two series of rocks is not determined, nor does it appear to be determinable from examinations thus far made within the State of New York."

Professor Hall makes a third unconformable series out of the limestone masses of that region, of which rock he says that it "unconformably overlies the upturned edges of the gneissic beds." He also further states that this limestone "does not conform to the upper or labradorite portion of the system." Hence, he considers that the limestone in question "does not belong to the Laurentian system, either lower or upper." He concludes by suggesting the inquiry "whether the Eozoon limestones of Canada, which are associated with Laurentian rocks, and have been referred to that age, are really Laurentian."

Professor Hall's idea of making a separate geological formation or system out of the limestone masses of Northern New York, on account of their unconformable position, is hardly less remarkable than that of Professor Emmons, who considered that the peculiar occurrence of this rock in the region in question could not be accounted for except on the supposition that they were of eruptive origin. It seems to us, on the other hand, that these limestone occurrences are, very probably, similar in character to those of Eastern Massachusetts, which are not a part of the stratified formation, but rather of the nature of segregated masses, or chemical precipitates, as will be more fully set forth farther on in this paper.

Prof. A. R. Leeds, in a paper entitled "Notes upon the Lithology of the Adirondacks," concluded

> "that the rocks of Essex County are part of the Norian System," and "that these norites are a stratified rock, but have undergone a metamorphosis so profound as to have caused them to be regarded by Prof. Emmons and earlier observers as unstratified. The dolerites which are found of the same constituent minerals, and are of the mean specific gravity of these norites, have probably been formed from a portion of these stratified deposits by deeply seated metamorphic action, and have further modified and greatly tilted the superposed rocks in the course of their extrusion." (American Chemist, 1877, VII., p. 339.)

That these rocks belong to the Norian system was determined by lithological evidence, which really means no more than this, that gabbros coming from different localities look somewhat alike. That the rocks are stratified is, according to him, shown by the existence of a more or less complete parallel arrangement of the constituent minerals. Professor Leeds is a chemist, and not a petrographer; and since his ideas are obviously simply a repetition of those of Dr. Hunt, his testimony neither adds to nor detracts from the importance of the theoretical views of the latter.

Mr. N. L. Britton, in 1881, in an article on the geology of Richmond County, N. Y., (Annals of the N. Y. Academy of Sciences, 1881, II., pp. 161–182,) advocates the view that the granite observed by him at Tompkinsville is an Archæan metamorphosed rock. This granite is said by him to be "very coarsely crystalline in structure," and no stratification is observable in it. No proof is furnished that it is of metamorphic origin.

The serpentine, which forms so conspicuous a feature in the geology of Staten Island, is thought by Mr. Britton to be a metamorphosed magnesian limestone. The sections drawn to illustrate the geology of the region show the serpentine always occurring as a sort of mantle enveloping the gneiss. These sections, which seem to be a pure fiction of the imagination so far as the relations of the serpentine and gneiss are concerned, do not agree with the geology as laid down on the accompanying map. Since, as is well known, a large part of the thoroughly-studied serpentines of the world have been proved to be the result of the metamorphism of eruptive masses, it seems more reasonable to ascribe such an origin to the rock in the region under consideration. At all events, the sections given do not favor the idea of such an origin of the serpentine as is advocated by Mr. Britton; nor is it by any means proven that the belt of metamorphic rocks which runs through Staten Island is, as he supposes, older than Lower Silurian.

NEW JERSEY.

In the Report of the earliest Geological Survey of New Jersey, by Prof. H. D. Rogers, the gneissic belt which traverses that State from northeast to southwest in its northern portion is called primitive, and the crystalline limestones which accompany it are supposed to be the result of an alteration of the Blue Limestone by the agency of dikes of granite. The beds or masses of iron and zinc ore, which characterize the gneissic belt, are said to be "unequivocally genuine lodes or veins." The later Survey, first under the direction of Dr. Kitchell, and later under that of Professor Cook, agree in making the crystalline limestones a portion of the gneissic formation. In regard to the iron ores, Professor Cook states (Geology of New Jersey, 1868, p. 44) that the majority of geologists now think them to be true beds, "which were deposited as sediments, in the same way as the material for the gneiss rock."

By Professor Cook the whole system of rocks, including the gneiss and crystalline limestones, together with the associated iron and zinc deposits, are considered as belonging to the "Azoic formation." These rocks are overlain, as represented in the published sections, by the

Potsdam sandstone in unconformable sequence. It was found by Professor Cook that it was not practicable to divide the Azoic of New Jersey, or to make of it "any other systematic classification than a geographical one." It will therefore not be necessary for us, in this connection, to dwell upon the geology of the lower rocks in this State. Since, however, this admirably conducted Survey is still in progress, and it will yet be possible to obtain from it valuable additions to our present stock of knowledge of that region, it will be well to call attention to certain points in regard to which evidence is still lacking to prove the correctness of the common belief about them.

The relations of the different Azoic rocks to one another should be most carefully studied, in order to find out whether the supposed gneiss is, as a whole or in part, sedimentary or eruptive, the laminated character not being sufficient to prove its origin, lamination being a very common character in eruptive rocks. The contacts of the rocks require very careful examination, as it is only in this way that it will be possible to make out the relative age, and in most cases the origin, of the rocks in question. Of the rocks, the first one in order of time should have its origin determined by study of its intimate structure, and by comparison of it with similar rocks of known formation. It would be necessary to remember that unconformability between the lamination or foliation of an eruptive rock, and the stratification planes of a sedimentary one, means something very different from the unconformability of two stratified deposits. Attention should be specially paid to the kind of contact made by the supposed Azoic with the Palæozoic, and examination should be made to see whether the latter at its base is composed of *débris* derived from the supposed Azoic. The one case in which the material of a conglomerate is referred to the gneissic rocks is a doubtful one, and, if correct, would only show that the gneiss is older than the Oneida conglomerate. (Geology of New Jersey, 1868, pp. 335, 336.)

In the case of the iron ores associated with the Azoic, the evidence given seems to be insufficient to prove the view either of their sedimentary origin or of their eruptive character. Statements in regard to the apparent conformable stratification and insensible passage of one rock into another have been often made, and are easy to make; but such statements require proof based on most careful observation, made by thoroughly skilled petrographers, before they can be accepted as conclusive evidence in regard to the question at issue.

PENNSYLVANIA.

The views of Prof. H. D. Rogers, former State Geologist of Pennsylvania, in regard to the lower formation in the region embraced within his Survey, have already been briefly mentioned.* Two years later than the date of the publication to which reference is there made — in 1858, namely — his Final Report appeared. In this Report, Professor Rogers adheres, essentially, to the ideas maintained by himself in the article in Johnson's Physical Atlas. In the introductory chapter to Part I. of the Final Report, under the heading of "Classification of the Metamorphic Strata of the Atlantic Slope of the Middle and Southern States," he discusses certain questions which pertain to the subject of this paper. He remarks, that, previous to the light thrown upon the older rock formations of the Atlantic Slope by the Geological Surveys of Pennsylvania and Virginia, these rocks were supposed to constitute but one group, and were included under the name of "Primary," and he then proceeds to make the following statement: —

> "Early, however, in the course of those surveys, it came to light that by far the larger portion of the rocky masses of at least the middle and northwestern tracts, including much of the Blue Ridge and of the Green Mountains, were of a different type and age from the oldest metamorphic or true gneissic system. The evidence in support of this conclusion was, first, an obvious and very general difference in the composition of the two sets of strata; secondly, a marked difference in their conditions of metamorphism; and thirdly, and more especially, a striking contrast in the direction and manner of their uplift, the plications and undulations of the less metamorphic series dipping almost invariably southeastward, while the gneiss in many localities has no symmetrical foldings, but only a broad outcrop dipping to a different quarter." (*l. c.*, pp. 62, 63.)

From the above statement it would appear that there could have been no difficulty, in the course of the Survey, of drawing the line thus said to be perfectly well defined by "*an obvious and very general difference in the composition of the two sets of strata,*" by "*marked differences in their condition of metamorphism,*" and finally, by "*a striking contrast in the manner and direction of their uplift.*" One is surprised to find, however, that all the above-stated differences were not realities, but "inductions," and that it was not "*until a relatively late date in the prosecution of the Geological Survey of Pennsylvania, that the geologist of that State detected positive evidences of this physical break, and of a lapse of time be-*

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* See *ante*, pp. 440, 441

tween the two groups of strata, and established, by ocular proof, the correctness of the previous induction."

In accordance with this latter statement, and not with the former, we do not find on the general geological map of the State accompanying the Final Report any indication of the two groups in question. All the crystalline rocks seem to be indicated by a single color, and included under the term "hypozoic."

Reading still farther in Professor Rogers's Report (*l. c.*, p. 63), we are even more surprised than before, when we learn that

> "Assembling all the evidence which we now possess, we have in the Atlantic Slope, by actual demonstration, but one physical break or horizon of unconformity throughout the whole immense succession of altered crystalline sedimentary strata, and within this region but one Palæontological horizon, — that, namely, of the already discovered dawn of life among the American strata. This latter plane or limit, marking the transition from the non-fossiliferous or azoic deposits to those containing organic remains, lies within the middle of the primal series or group of the Pennsylvania survey, that is to say, in the primal white sandstone. . . . . The Primal slates beneath the sandstone, and in intimate alternation with it, possess not a vestige of organic life, nor has any such been yet discovered anywhere within the limits of the Atlantic Slope, or on the northern or western borders of the Great Appalachian Basin of North America."

Farther on in his Report, Professor Rogers remarks concerning his two systems of rocks, — the Hypozoic or Gneissic, and the Azoic, — that "the members of the two groups often simulate each other so closely, and *are indeed so identical in mineral aspect and structure, as to baffle all attempts at distinguishing them lithologically.*" Again, we are informed that these systems are nevertheless distinct from each other, and "susceptible of delineation on the geological map." But, it is immediately added, "the State geologist did not venture to define them on the map."

Before proceeding to notice the results attained by the Second Geological Survey of Pennsylvania, in connection with the investigation and classification of the crystalline rocks of that State, it will be well to refer to the views published by Dr. Hunt at various times between the completion of the First Survey and the beginning of the Second. This is the more desirable, because he was employed by the State Geologist (Professor Lesley) "*to collate all the known, supposed, and suspected facts of American Azoic Geology*" for publication by that Survey, apparently as a sort of manual or guide to the mysteries of that department of the science, for the use of future investigators. Professor Lesley considers that "a debt of gratitude is due Dr. Hunt for his historical monograph," although admitting that "no final demonstration has been accomplished by the author [Dr. Hunt] of those problems of superposition, unconformability, and identification, at which so many geologists are still half despairingly at work." (Azoic Rocks, p. vii.) Perhaps this admitted want of success will not be so difficult to account for. when one takes into consideration some of the views published by Dr. Hunt previous to his engagement on the Pennsylvania Survey.

In 1861, Dr. Hunt remarked, regarding the Hypozoic or Gneissic series of Professor Rogers (Am. Jour. Sci., 1861, (2) XXXI., pp. 394, 395): —

> "We have along the great Appalachian chain, from Georgia to the Gulf of St. Lawrence, a third series of crystalline strata, which form the gneissoid and mica slate series of most American geologists, the hypozoic group of Prof. Rogers, consisting of feldspathic gneiss, with quartzites, argillites, micaceous, epidotic, chloritic, talcose and specular schists, accompanied with steatite, diorites and chromiferous ophiolites. This group of strata has been recognized by Safford in Tennessee, by Rogers in Pennsylvania, and by most of the New England geologists as forming the base of Appalachian system, while Sir William Logan, Mr. Hall, and the present writer have for many years maintained that they are really altered palæozoic sediments, and superior to the lowest fossiliferous strata of the Silurian series. Sir William Logan has shown that the gneissoid ranges in Eastern Canada have the form of synclinals, and are underlaid by shales which exhibit fossils in their prolongation, while his sections leave no doubt that these ranges of gneiss, with micaceous, chloritic, talcose and specular schists, epidosites, quartzites, diorites and ophiolites, are really the altered sediments of the Quebec group, which is a lower member of the Silurian series, corresponding to the Calciferous and Chazy formations of New York, or to the Primal and Auroral series of Pennsylvania. Prof. Rogers indeed admits that these are in some parts of Pennsylvania metamorphosed into feldspathic, micaceous and talcose rocks, which it is extremely difficult to distinguish from the hypozoic gneiss, which latter, however, he conceives to present a want of conformity with the palæozoic strata. To this notion of the existence of two groups of crystalline rocks similar in lithological character but different in age, we have to object that the hypozoic gneiss is identical with the Green Mountain gneiss, not only in lithological character, but in the presence of certain rare metals, such as chrome, titanium, and nickel which characterize its magnesian rocks; all of these we have shown to be present in the unaltered sediments of the Quebec group, with which Sir William Logan has identified the gneiss formation in question. Besides which the lithological and chemical characters of the Appalachian gneiss are so totally distinct from the crystalline strata of the Laurentian system, with which Prof. Rogers would seem to identify them, that no one who has studied

the two can for a moment confound them. Prof. Rogers is therefore obliged to assume a new series of crystalline rocks, distinct from both the Laurentian and Huronian systems, but undistinguishable from the altered palæozoic series, or else to admit that the whole of his gneissic series in Pennsylvania is, like the corresponding rocks in Canada, of palæozoic age."

In the Presidential Address of Dr. Hunt before the American Association, 1871, it is stated that Prof. H. D. Rogers has distinguished three districts in Pennsylvania of various crystalline schists, which, in his Report on the geology of that State, he included under the name of Gneissic or Hypozoic rocks. The gneiss of the northern or South Mountain belt is said by Dr. Hunt to be "lithologically as well as geognostically identical with that of the Highlands, and belongs like it to the Adirondack or Laurentian system of crystalline rocks." The gneiss of the middle district seems to be regarded as Laurentian, while that of the third or southern district is referred to the White Mountain series, with the exception of the middle subdivision, which is said to present the aspect of the second or Green Mountain series.

Professor Rogers is stated to have placed above the hypozoic gneisses his azoic or semi-metamorphic series, which Dr. Hunt regards as belonging to the Green Mountain or Huronian series, in regard to which he remarks as follows : —

> "The azoic or so-called metamorphic primal strata are said to have a very uniform, nearly vertical, dip, or with high angles to the southward, while the micaceous and gneissic strata of the northern subdivision of the southern district of so-called hypozoic rocks, limiting these last to the south, present either minute local contortions or wide gentle undulations, with comparatively moderate dips, for the most part to the northward. From this, I think we may infer that the nearly vertical strata must be, in truth, older underlying rocks, belonging, not to the palæozoic system, but to our second series of crystalline schists." (Proc. Am. Assoc. Adv. Sci., 1871, XX., pp. 7–9.)

It seems, although we were, in 1861, emphatically informed that the "*lithological and chemical characters of the Appalachian gneiss are so totally distinct from the crystalline strata of the Laurentian system, ... that no one who has studied the two can for a moment confound them,*" that now we are as positively told that part of it is "*lithologically as well as geognostically identical with . . . . [the] Laurentian system of crystalline rocks.*"

In 1875 Prof. J. P. Lesley stated that the Huronian or Green Mountain series seems to overlie the White Mountain series in the vicinity of Philadelphia; also, that the conglomerate beds of the Primal series hold pebbles of Huronian rocks. (Second Geological Survey of Pennsylvania, D, p. 66.)

In 1876, he says that the middle zone of gneiss of Rogers is "now known to be Laurentian." (*l. c.*, A, p. 136). It is well known that in general Dr. Hunt claims a reverse order, or that the Montalban overlies the Huronian.

In 1876 Dr. Hunt referred the ores, found along the borders of the Mesozoic red sandstone, and including the Cornwall mine, to the Lower Taconic (Taconian); but no evidence was given to show the justness of this conclusion. (Trans. Am. Inst. Min. Eng., 1876, IV., p. 320.)

During this year he also referred other rocks in Pennsylvania to the Laurentian, Huronian, and Montalban. This determination seems to have been based exclusively on lithological characters, no further evidence except difference in the strike of their supposed stratification planes being advanced. The Primal slates and sandstones of Rogers were regarded by Dr. Hunt as Lower Taconic (Taconian). (Proc. Am. Assoc. Adv. Sci., 1876, XXV., pp. 208–212.) He also makes the White Mountain (Montalban) series in the vicinity of Philadelphia to overlie the Huronian, although Professor Lesley states that the reverse appears to be the case.

In Professor Frederick Prime's Report (Second Geological Survey of Pennsylvania, DD, 1878) the gneissic rocks in Lehigh County are called Laurentian. In one locality he says that

> "the junction of the Potsdam sandstone and Laurentian rocks can be well seen. The dips of the two rocks seem to be conformable, but this may be wrong, as the exposure is small and the gneiss apparently has a slight roll. The gneissic rock is here distinctly bedded."

It is probable that Professor Prime uses the term "distinctly bedded" for "distinctly foliated," terms which have not as yet been proved to be synonymous. He further says: —

> "It is possible that these gneissic rocks which seem to lie conformably with the sandstone, and which are true gneisses, are in reality Lower Potsdam." (*l. c.*, pp. 9, 10.)

In 1877, Professor Prime advances some evidence to show that the Potsdam sandstone was deposited upon the gneiss and made out of its ruins; had he deemed this determination a matter of as much importance as it seems to us to be, he would doubtless have investigated the matter more closely. It is to be hoped that this may yet be done. He shows that the mica schists (hydro-mica slates) lie between the Potsdam sandstone and Magnesian limestone, conformable with both, and that they therefore cannot belong to the "Taconian" of Hunt, as the latter had stated. Professor Prime also says: —

> "It is well here to emphasize the fact that these brown hematite ores all belong to the Lower Silurian limestone formation, since, in 1875, Dr. Sterry Hunt, after a cursory examination of Ziegler's Mine in Berks County . . . . made the mistake in a paper on 'The Decay of Crystalline Rocks' before the National Academy of Science, of supposing that the hydromica slates belonged to the Huronian Period: — a mistake into which so eminent an observer as himself would never have fallen had he been better acquainted with the region." (Proc. Am. Phil. Soc., 1878, XVII., pp. 248–254; Am. Jour. Sci., 1878, (3) XV., pp. 261–269.)

Mr. Charles E. Hall thus indicates the formations of Eastern Pennsylvania, in their ascending order (Proc. Am. Phil. Soc., 1880, XVIII., pp. 435–443): —

> *First.* A series of granitoid, syenitic, quartzose, and micaceous schistose rocks.
>
> *Second.* A series of syenitic, hornblendic and quartzose rocks. He states, however, that "this series may be the upper members of the first."
>
> *Third.* Potsdam sandstone, conglomerate, quartzite, and occasional schistose beds. "This, the Potsdam sandstone, rests unconformably upon the preceding two groups. The unconformity is seen at points east of Willow Grove, where the lower conglomerates contain fragments of the syenitic rocks."
>
> *Fourth.* Dolomites, schistose or slaty micaceous beds, limestone, marble, hydromica schists, and bastard marble. "This group of limestones and schists rest on the above group, and are the equivalent of the Cambrian limestones of the Great Valley."
>
> *Fifth.* Hydromica schists, quartzose schists, chloritic schists, and occasional beds of quartzites and sandy beds and serpentines.
>
> *Sixth.* Micaceous, garnetiferous schists, limestone, mica schists and sandstones. "This group rests unconformably upon the western extension of the *second* group."
>
> *Seventh.* "The mica schists of Philadelphia, mica schists, hornblendic, garnetiferous, talcose schists with soapstone and serpentine. . . . . They rest unconformably upon the first, second, third and fourth groups. . . . . There are besides these groups probably two serpentine horizons, which are undoubtedly unconformable deposits above the second group. I think the northern belt of serpentine may be considered as altered Hudson river rock; while the southern belts are doubtful."

The slates of Chester, York, and Lancaster Counties (including the Peach Bottom slates), as well as the serpentines of Radnor, Easttown, Willistown, and East and West Goshen, are stated to be undoubtedly of Hudson River age. (See also Am. Jour. Sci., 1880, (3) XIX., pp. 413, 414.)

From the above it will be seen that Mr. Hall makes his first and second groups — which, however, he seems to think may perhaps belong together — to be older than the Potsdam Sandstone, which overlies them unconformably. None of the rest of his groups can, therefore, be of Azoic age. This is a result very different from that attained by Dr. Hunt and others, who have made most of this region pre-Silurian. But Mr. Hall's views seem to have a substantial basis of observation, while Dr. Hunt's cannot be regarded as anything more than theories based on lithological resemblances. How fanciful these are may be inferred from the contradictory statements of that author himself in regard to the rocks in question.*

By way of illustrating the difficulty of separating the lower formations from each other in the crystalline belt of Pennsylvania, it may be well to add one or two extracts from the latest publication of the present Survey of that State; — "The Geology of Chester County, after the Surveys of Henry D. Rogers, Persifor Frazer, and Charles E. Hall. Edited by J. P. Lesley [State Geologist], C^4, 1883." In this publication two maps are given, one of which embodies the conclusions reached by Professor Rogers, the other those of Mr. C. E. Hall, the region embraced in these maps being essentially the same, and forming part of Delaware and Chester Counties. A comparison of these maps will show how utterly unlike they are; but perhaps it will be better to quote Professor Lesley's own language on this point. He says (*l. c.*, p. viii.): —

> "It is impossible to imagine a greater contrast than between these two illustrations of opposite views. The great regularity of Mr. Rogers' belts, the utter irregularity of Mr. Hall's areas, strikingly exemplify the difference between the conclusion arrived at, in a difficult region like this, by the earlier geologist who made everything bend to his theory of parallel overturned anticlinals and synclinals, and the observations of the later geologist who is fettered by no such theory, but is perhaps quite as strongly influenced by a different sentiment, viz.: that the Azoic formations spread out over one another with moderate inclinations unconformably."

Furthermore, the following may be quoted from the same source, as illustrating the facts that even the later geologists — those, namely, who have worked longest and most perseveringly in this difficult field — have not been able to arrive at concordant results. Professor Lesley remarks (*l. c.*, p. 34): —

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* See *ante*, pp. 469, 470.

"Since 1858 the district in question has been closely and repeatedly investigated by Prof. Frazer and Mr. Hall, the one approaching it from the west, the other from the east. They differ radically in their views of the order and superposition of the formations, not only from Prof. Rogers, but from each other; so that this report will leave several points of geology in almost as great obscurity as ever."

Finally, the following may be commended to the consideration of the reader (*l. c.*, p. 53):—

"It will be seen from the summary of Prof. H. D. Rogers' observations in 1851, given above, that he was guided everywhere by a theory of parallel *anticlinal folds* in the great Azoic or Hypozoic strata; and of intermediate *synclinal troughs*, some of them wide and deep, others narrow and shallow, but all of them containing preserved remnants of more micaceous strata, of a later age, but probably older than the hydro-mica slates of the South Valley hill. In no respect however does he settle the great question of what the true relationship may be between the older and newer gneisses,—between the newer gneisses and the talc-mica-schists,—between the talc-mica-schists and the sandstone (quartzite)—between the quartzite and limestone—between the limestone and serpentine—in the southern townships of Chester county. After an apparently copious and precise array of facts the geology of the whole district remains as confused and obscure as ever. The section along the Schuylkill is the key to the lock; but the key will not turn in the lock; the door remains closed. . . . . We travel to and fro across the hills and find no clue to guide us out the labyrinth of infinitely various and yet strangely similar deposits, the strike of which is everywhere more or less doubtful to the eye and tempting to the imagination."

VIRGINIA.

Prof. W. M. Fontaine states that certain coarse syenites and granites in the vicinity of Balcony Falls and the Peaks of Otter, "from their stratigraphical relations and composition," are plainly of Laurentian age. These rocks appear to be regarded by him as being eruptive in many places. Since he assumes without any apparent evidence, except the "*look*" of the rocks, the passage of sedimentary rocks into remarkable metamorphic forms, and also that other rocks are eruptive from the same evidence (their "looks"), his statements relating to crystalline rocks need in most cases to be accepted with caution until the proof is presented. It is doubtful if the supposed primordial rocks are of that age. Should they hereafter be shown to be Primordial, all that Professor Fontaine's evidence shows is an older series of rocks containing eruptive granites, syenites, etc. His writings are far from being clear, but we are unable to find any proof in them that the granite and syenite are of different geological age from their associated rocks. (Am. Jour. Sci., 1875, (3) IX., pp. 14–22, 93–101, 361–369, 416–428.)

It would appear that Prof. J. L. Campbell regards the Laurentian granites and syenites of Professor Fontaine as eruptive rocks, erupted since the deposition of the supposed Primordial strata, thus leaving only one formation *in situ* under the supposed Primordial. Professor Campbell holds, however, that the eruptive syenites and granites are metamorphosed, and displaced underlying formations. In another locality he seems to regard the syenite as a "syenitic gneiss (or stratified syenite), which might readily be taken for an igneous rock — so greatly has it been metamorphosed"; but he fails to give any evidence that it is not igneous, or any reasons why it should be regarded as a metamorphosed sedimentary rock. He also fails to show that the supposed Primordial is composed of the *débris* of his supposed Archæan. As has been before remarked in other similar cases, it is not here our intention to assume that the conditions are not as they are assumed to be; it is simply our wish to call the attention of the observers to the fact that their published observations fail to furnish the proof necessary to be presented before these ideas can be accepted as axioms. They are not of the nature of self-evident truths. (Am. Jour. Sci., 1879 (3) XVIII., pp. 16–29, 119–128, 435–445.)

The latest setting forth of Professor Fontaine's views on the subject here under discussion will be found in a letter from himself to Professor Lesley, dated January 20th, 1883. (Second Geological Survey of Pennsylvania, Report, C^4, 1883, pp. xiii.–xvi.) In this letter he clearly assumes that the division of the Azoic rocks into Laurentian and Huronian is to be taken for granted as something so clearly established that it must stand, no matter how difficult it may be to reconcile the theory with the facts. The Huronian seems to be wanting; that is, he finds it very difficult to discover rocks having the proper lithological characters. Thus he says (*l. c.*, p. xiii.): —

> "The Blue Ridge in the northern part of Virginia is, as I take it, much as it is in your South Mountains of York, &c. The Huronian strata hide very largely the Laurentian. On the Potomac the latter does not show at all. . . . . The Laurentian sinks and expands as we go south in Virginia, and often has over it a mere remnant of the Huronian. . . . . Still farther south-

ward, in the counties of Floyd and Carroll, I could find no typical Huronian, such as the chlorite rocks, the felsite, &c."

Throughout the whole of this communication it appears clearly that Professor Fontaine considers that the terms Huronian and Laurentian are simply names for certain lithologically peculiar rocks. Chlorite schists are called "typical Huronian," and gneisses "Laurentian"; but it is easy to see from his description that the two, with the other ordinarily associated rocks, occur together, sometimes one predominating and sometimes another, in a manner perfectly characteristic of the Azoic series as a whole, yet utterly in opposition to their existence as separate and distinct systems.

NORTH CAROLINA.

In the Report of Prof. W. C. Kerr on the Geology of North Carolina (1875), a large portion of the rocks of that State is assigned to the Laurentian and Huronian formations. Three distinct belts of Laurentian are recognized. The eastern one

> "consists of light colored and grey gneisses, which occasionally pass into granite, but more frequently into felspathic, quartzose (and rarely hornblendic) schists. In some localities the mica is entirely wanting, and then the rock is either a dull-reddish, brownish, or whitish massive felspathic rock, trachyte, euryte, felspar porphyry, &c." (*l. c.*, p. 122.)

The Edgecombe granite, which Professor Kerr regards as a metamorphosed sedimentary rock (gneiss), "shows no gneissic or foliated structure, being undistinguishable from true granite."

In the second area (*l. c.*, pp. 123–128), —

> "the characteristic and prevalent rocks are syenyte, doleryte, greenstone, amphibolyte, granite, porphyry, and trachyte . . . . The most common rock is of a hornblendic character; and traps, trachytes, granulytes and porphyries are confusedly and angularly wedged in among each other, with frequent veins of epidote crossing the felspathic species in every direction. . . . . The absence of anything like stratification or foliation is conspicuous throughout the region. . . . . If there be any significance in structure or in lithological characters, this singular body of rocks seems entitled to be placed at the very base of the Archæan age, certainly at the bottom of the Laurentian; and even below these, if there be any older rocks exposed anywhere, — the true Azoic or

Igneous. In the direction of this notion certainly point the absence of stratification, the non-occurrence of limestone, and the great predominance of syenytes (mostly hyposyenyte), and other iron-bearing and basic rocks. I have only placed them as the lower Laurentian, however, since there seems to be a general disinclination to suppose that the primal igneous core anywhere shows itself to human inspection. This belt may well be characterized as the geological axis of the State. The group of rocks just described is bounded on the northwest by a series of gneisses and feldspathic and occasionally hornblendic slates, which extend westward with little interruption to the Blue Ridge, and, except a narrow zone of a few miles breadth along the course of that chain, includes the whole mountain region to the flanks of the Smoky Mountains, through the greater part of its length. These are considered to belong to the Laurentian proper. . . . . A few miles west of this is a narrow terrane of syenytes and other hornblendic rocks and granites. . . . . The predominance of hornblendic rocks, the absence of mica, and the general absence of stratification have seemed to justify the reference of this belt to the lower part of the series, along with the preceding central zone. . . . . Another considerable area of Laurentian rocks is found beyond the Blue Ridge, occupying most of the mountain plateau between that and the Smoky Mountains, and in places constituting the materials of these chains. As stated before, this area may very properly be considered as only a continuation of the preceding, from which it is divided by a very narrow and interrupted belt of Huronian slates. . . . . The rocks of both of these, like those of the preceding area, are foliated for the most part, and consist of indefinite alterations of the same kinds of metamorphic strata, — gneiss, hornblendic, feldspathic and micaceous schists, and occasionally chloritic and talcose slates."

In regard to the principal Huronian belt, Professor Kerr makes the following statement (*l. c.*, p. 133) : —

"The belt is bounded on both sides by the Laurentian, already described, on which it lies unconformably, and from which its materials were derived. The stratigraphy therefore indicates the horizon of these rocks to be the Huronian, and the lithology agrees well with that determination; and the reasonable course therefore seems to be, to place them as Huronian, until some evidence shall be found of an organic character, to lift them to a higher geological plane. The absence, or at least the non-discovery of fossils hitherto, in an extensive body of slates like those of the middle and west portions of this tract, so little altered and so well adapted to the preservation of even the most delicate organisms, and in a region so much studied, and on account of numerous mines, offering so good opportunities for the discovery of fossils if any existed, is certainly so far confirmatory of the sub-Silurian theory of these deposits. This is the principal area of Emmons' Taconic in this State."

Prof. F. H. Bradley, however, who had made a special study of the rocks of Eastern Tennessee, subsequently examined a considerable portion of Western North Carolina, as well as the adjacent regions of Georgia and Alabama. In a series of papers entitled " On the Silurian Age of the Southern Appalachians," (Amer. Jour. Sci., 1875, (3) IX., pp. 279–288, 370–383,) this geologist reaches conclusions which he thus states : —

> " The rocks of that portion of North Carolina south and west of the Little Tennessee, together with the metamorphic area of Georgia, north of a line parallel with and ten miles south of the Chattahoochee (and *probably* that south of this line), and the entire metamorphic area of Alabama, are *Silurian or newer*, with the possible exception of two or three small patches not over ten miles in diameter." (*l. c.*, p. 280.)

Professor Kerr acknowledges that, if Professor Bradley's identifications prove valid, it will probably be found that all the Huronian rocks except those of the middle and eastern belts will prove to be Silurian. Of these he remarks (*l. c.*, p. 140) : —

> " But this conclusion will not involve the great middle and eastern belts which must still remain Huronian, until determined independently to belong to a later series ; both because they are widely separated from the others, and because they have lithological and stratigraphical characters of their own, which would prevent their following any determinations of horizon for the others, which should be based on these considerations alone."

In regard to an area adjacent to Tennessee, Professor Kerr says (*l. c.*, p. 139) : —

> " This belt of rocks is colored on the map throughout like the other Huronian belts, and for the same reasons, viz. : that they succeed the Laurentian, and differ from them strongly in degree of metamorphism and general lithological character, so that the transition from one to the other is obvious along the whole extended line of contact, and that they have yielded no fossils, which alone could authorize their reference to a later age. And although the fact of unconformability can not be asserted for any one of the sections, this may arise from the circumstance that the disturbance and dislocation of the strata along this line are extreme, and that no detailed or minute examination has ever been attempted, and of course nothing short of such examination would suffice in such a region. And another circumstance of weight is the immense body of these rocks, which must be allowed, on the French Broad for example, after every reasonable reduction for folding, a thickness of several miles. Add these to the primordial or the lowest members of the Lower Silurian, and they receive a most incredible development downwards, since the rocks along the Tennessee border referred to this horizon have already a very great thickness. However, as stated above, these rocks have only been located *provisionally*. And it is right to say further that the only examination I have made of this western Smoky belt, was a mere reconnoisance, mostly on horseback, made in a few weeks in the autumn of 1866."

In 1878 Dr. Hunt referred part of the gneisses of North Carolina to the Laurentian, but found "indications of a belt of Huronian schists," while the "thin bedded gneisses with highly micaceous and hornblendic schists," which Professor Kerr had regarded as Laurentian, he referred to the Montalban.

It results quite clearly from the study of what has been published by Professors Kerr and Bradley, that there has been no satisfactory reference of any of the rocks of North Carolina older than the Triassic to their proper place in the geological series. Professor Kerr's Laurentian and Huronian include all the existing stratified formations in that State below the Trias, and, judging from what is known of the geological structure of the Appalachian belt farther north, it is highly probable that Professor Bradley was right in referring a considerable portion of the metamorphic rocks of North Carolina to the Palæozoic. At all events, it is safe to say that, with our present uncertainty in regard to the geological age and structure of the region in question, there can be no reason for dividing the older rocks into Laurentian and Huronian other than on purely theoretical grounds.

SOUTH CAROLINA.

But little is known in regard to the older crystalline rocks of South Carolina. Mr. Lieber, the former State Geologist, describes different varieties of them; but he gives no clue to their geological position, and but little information is afforded as to their order of succession. Dr. Hunt, however, has endeavored, on the basis of Mr. Lieber's description, to range the various rocks of this State within the systems described by him as occurring farther north. He says (Proc. Am. Assoc. Adv. Sci., 1871, XX., pp. 10, 11): —

> "It is easy, from the reports of Lieber on the geology of South Carolina, to identify in this State the two types of the Green Mountain and White Mountain series. The former, as described by him, consists of talcose, chloritic, and epidotic schists, with diorites, steatites, actinolite-rock, and serpentines. . . . . The great gneissic area of Anderson and Abbeville districts is described by Lieber as consisting of fine-grained gray gneisses, with micaceous and hornblendic schists, and is cut by numerous veins of pegmatite, holding garnet, tourmaline, and beryl. These rocks, which have the character of the White

Mountain series, appear, from the incidental observations to be found in Lieber's reports, to belong to a higher group than the chloritic and serpentine series, and to dip at comparatively moderate angles."

We have not been able to find in Mr. Lieber's reports any evidence that the gneissic rocks of Abbeville and Anderson districts were considered by him as newer than the chloritic and serpentine series. On the contrary, the granites and gneisses are again and again stated to be the oldest rocks in the State.

GEORGIA.

In Georgia, according to Dr. George Little, the State Geologist, there are no Azoic rocks; but Dr. Hunt on lithological grounds referred some gneisses (granites) to the Montalban, and some slates probably to the Taconian.

TEXAS.

Mr. S. B. Buckley, State Geologist, in his various reports, describes various forms of eruptive, crystalline, and metamorphic rocks as occurring in that State. In his First Annual Report he defines the Azoic as follows: —

> "The Azoic are igneous rocks, destitute of animal and vegetable matter, thrown up from below, or rocks altered by contact with such melted matter. . . . . Some of the Azoic rocks are the oldest known, and others not, for there are granites in Texas, ... which have been thrown up during the formation of the rocks of the older Silurian." (*l. c.*, pp. 15, 16, 76.)

In his Second Report, Mr. Buckley recognizes two distinct ages — the Azoic and the Eozoic — as forming "Archæan time." In the Azoic he includes the granites and their associated rocks destitute of fossils; viz. shales, mica schists, gneiss, hornblende, porphyries, etc. There are said to have been two or more periods of the upheaval of the granites, one probably later than the Cretaceous.

Since it is so evident that Mr. Buckley under the head of Azoic includes rocks of very different ages, it will not be necessary for us to dwell at large upon his work, which is of no importance in reference to the question before us. The views he appears to hold with regard to the eruptive and older stratified rocks in general are quite analogous to those of Prof. C. H. Hitchcock, which have already been presented, as well as to those of the geologists of the Fortieth Parallel Survey, to which reference will be made a little farther on.

TENNESSEE.

Prof. J. M. Safford, in his first Report on the Geology of Tennessee, 1856, referred the metamorphic rocks of the State to the Azoic, separating them into two series: the semi-metamorphic, and the metamorphic. In the Final Report (1869) the metamorphic rocks were regarded as Azoic or Eozoic; but he states that they can be traced in part to unmetamorphosed beds, and from what follows it will be seen that he regarded them as in part formed from and in part conformably underlying the Ocoee group, which he referred to the Potsdam. He says of the metamorphic rocks of the State: —

> "With reference to age, I have no reason for believing that this group, within Tennessee, includes the metamorphosed beds of any formation of more recent date, than the Ocoee Conglomerate and Slates. A portion of the beds are certainly referable to the Ocoee Group; the remainder, although conformable, may be older, and most likely are. There are sections which show clearly the change of the conglomerate, and its associated rocks, into gneiss and mica, and other slates. In approaching, for instance, the Ducktown region, from the west, the pebbles of the conglomerate gradually lose their forms, becoming more and more, small, shapeless masses of quartz, and yet discernible, even when the gneissoid or complete metamorphic character is seen. In the northern part of the State, at many points, the passage of the Ocoee beds into gneiss, is gradual and apparent. A considerable part, indeed, of our metamorphic rocks, can be, I think, thus referred to these beds. The question as to the greater age of other parts, is not so easily settled, and must remain open for the present. I know of no sufficient reason for referring any of these rocks to the Huronian or Laurentian series of Canada." (*l. c.*, pp. 177, 178.)

Prof. Frank H. Bradley holds that all the metamorphosed rocks in Tennessee were Silurian. (Am. Jour. Sci., 1875, (3) IX., pp. 279–288, 370–383.)

ARKANSAS.

It appears that Dr. David Dale Owen regarded the crystalline rocks of Arkansas as eruptive, stating that the sedimentary rocks have been shattered, uptilted, and broken by them. He also gives localities in which they overlie the slates. His evidence, what there is of it, would indicate the correctness of his views, but it is far from being as complete as would be desirable.

MISSOURI.

There is no published evidence showing that the crystalline rocks of Missouri proved to be older than the Silurian are of different ages, or that most of them are not eruptive. They have been assigned to the Laurentian and Huronian, but solely from their lithological characters.

MICHIGAN AND WISCONSIN.

A short time ago a discussion of the various theories regarding the crystalline rocks of the region adjacent to Lake Superior, and especially its southern shore, was published by one of the authors of the present paper.* In that work the evidence by which the theories in question have been sustained was pretty thoroughly examined, and it now remains, therefore, only to add that which is necessary in order to bring the discussion down to the present date. Some little repetition and recapitulation will, however, be advisable, in order that the reader of this paper may have a clearer idea of the points here discussed.

The copper-bearing rocks of Lake Superior have been considered by some geologists as a distinct formation, older than the Potsdam sandstone adjacent to which it lies. The principal evidence in support of this opinion was supposed to have been obtained at the falls of a branch of Torch River, known by the name of Douglass Houghton. Here the trappean or cupriferous series was said to end, and to have abutting against its edges strata of the Potsdam. The latter was also said to contain fragments of the other, necessarily older, rock. These facts were thought to prove that the copper-bearing rocks formed a sea-shore bluff, along the base of which the sandstone was deposited with its trappean fragments. In order that the reader may understand the condition of things at that point, it will be necessary for us to indicate the structure of the copper-bearing rocks themselves. They consist of a series of old lava flows (diabase and melaphyr), intercalated between beds of conglomerate and sandstone. The traps are known to be lava flows, by the baking and induration of the immediately underlying rock; by the fact that tongues and dikes extend from the overlying trap down into the rock beneath; by the scoriaceous character of the upper portion of the traps, and the coarser crystallization of their lower parts; by the macroscopic and microscopic evidences of flowing, etc. That they in each case were *in situ* before the immediately overlying rock was deposited, is shown by the facts that they have not affected it in any way, and that they present on their upper surface the irregularities and rounded knobs which lava flows are known to have, especially when exposed to water action; by the presence of rounded fragments of the underlying trap enclosed in the overlying conglomerate; by the absence of fragments of the overlying rock in the underlying one, and by the absence of any marks of intrusion of the traps between different beds.

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* Notes on the Geology of the Iron and Copper Districts of Lake Superior. By M. E. Wadsworth. This Bulletin, *ante* [Vol. VII., or Geol. Series, Vol. I.], pp. 1–157.

Sometimes the lava flow was followed by another, without any apparent long exposure of the former; then again the interval between the two succeeding flows was so great, that sandstones and conglomerates having a thickness of from a few inches to half a mile (Marvine) were deposited between them. Of course from this it followed that the surface of the underlying trap suffered denudation, and that afterwards the conglomerate was deposited unconformably upon it. This was the general mode of formation throughout the series on Keweenaw Point. The general condition of things may be correctly indicated by the statement, that in going from the east towards the west the cupriferous series is found to be made up of an increasing number of lava flows and a diminishing number of conglomerates, until a point is reached where the volcanic activity culminated, when the flows diminished and the conglomerates increased, until the Western sandstone was reached. It would follow from the mode of formation, that whenever a sandstone or conglomerate was laid down on the trap, denudation of the latter would take place and fragments of it be enclosed in the unconformably overlying detrital rock; and this would hold good not only of the intercalated beds, but also of the Western sandstone. All these evidences of denudation would then be merely signs of sequence of time, and not of a difference in geological age. Precisely similar facts may be observed at the present day wherever a lava flow has an opportunity to reach the shore of the sea.

The question, then, whether the copper-bearing rocks are a formation of a geological age older than the Lake Superior sandstone, is to be ascertained, if at all, on the eastern, and not on the western side. It has just been pointed out on what evidence the Eastern sandstone was said to be younger than the traps; but a careful examination of the region in question showed its incorrectness. At the Douglass Houghton Falls the stream passes over a cliff of trap, and then winds through a gorge having high and very steep banks. It was very natural that, in ascending this stream from Torch Lake to the Falls, the hasty observer should be led to believe that the sandstone and conglomerate extend in an unbroken band up to the cliff at the latter locality, and regard it as an old sea-shore bluff. This would especially be the case should he confine his observations to the stream, and not attempt to explore the clayey, slippery, difficult sides of the ravine. The writings of previous observers give no evidence that they did more than to follow the bed of the stream; and they all concurred in stating that the sandstone was horizontal, or nearly so, up to the Falls, at which place the trap was said to be first met. When Dr. Wadsworth examined the locality, in 1879, he not only explored the bed of the stream, but also the bluffs on both sides. These examinations showed that the sandstone and conglomerate were not horizontal, but that they had a gradually increasing dip as the Falls were approached from 5° up to 25°, while on both sides of the stream the traps were found holding the same relations to the sandstone and conglomerate that they have been stated to hold elsewhere in the series. These traps had been masked and concealed by the falling rock and earth; but, on digging, foot after foot of the junctions of a number of the lava flows and their adjacent sandstones were exposed. The flow nearest Torch Lake is about two feet in thickness, lying between two beds of sandstone, all having a dip of 20°. Junctions of these beds and the flow were exposed by excavating along a distance of about twenty feet. The trappean pebbles seen by former observers at the Falls were seen to have been derived from the underlying trap, as they are throughout the entire series, and not from the supposed old sea-shore bluff. In the same way, the sandstone and conglomerate were carefully followed up by the Hungarian River from Torch Lake, and the same condition of things observed. (*Ante*, pp. 113–116.)

These observations are of a kind to exclude any probability of a mistake; they are clear, and definite. Moreover, they explain the errors of previous observers, and until refuted, if they can be, they conclusively show that the Eastern sandstone and the copper-bearing series are one and the same geological formation, although differing in time sequence. It is a remarkable circumstance, that, while this evidence is so clear and explicit, the more recent writers have carefully avoided any mention of it, but have endeavored to discuss the subject on theoretical grounds chiefly.

It now becomes necessary to follow in greater detail some of the writings of others previous to 1879 and later, owing to the importance claimed for them in the more recent discussions. The first to demand our attention is a paper by Prof. R. D. Irving on the relations of the Huronian, Keweenawan, and Potsdam Series. He states (Trans. Wisc. Acad. Sci., 1873–74, II., pp. 117–119): —

> "The conclusions, then, that I would draw are these: —
>
> "1. The Copper Bearing and Huronian Series were once spread out horizontally one over the other, and owe their present highly tilted position to one and the same disturbance.
>
> "2. That subsequently — after a long period of erosion — the horizontal Silurian sandstones were laid down over, and against the upturned edges of the Copper Bearing Series, filling also the synclinal, in Ashland county, which lies between the northward and southward dipping sandstones.
>
> "3. That hence the Copper Bearing Series is more nearly allied to the Archæan, than to the Silurian rocks.
>
> "One fact observed, however, seems at first difficult of explanation on this hypothesis. In Douglas county, as already said, the horizontal sandstones can be traced to their exact junction with the southward-dipping traps. But, in several places, the sandstones present a very remarkable change as the trap is approached. On passing up the gorge of Black River, whose sides are perpendicular exposures of rock over one hundred and fifty feet in height, towards the south, the horizontal layers of sandstone are suddenly seen to change from their ordinary position to a confused mass of broken layers, dipping in every conceivable direction, and increasing in confusion as the trap is approached, until, finally, the whole changes to a confused breccia of mingled trap and sandstone fragments. This appearance is presented along both sides of the gorge, for a distance of 300 feet, and I am assured by my assistant, Mr. E. T. Sweet, by whom all observations in Douglas county were made, that it is certainly due to no mere surface misplacement. The same appearance is presented on one of the other northward flowing streams in Douglas county, on a

much diminished scale however, the undisturbed sandstones reaching within twenty feet of the trap. On all other of these streams, the sandstone is undisturbed. The explanation which first suggests itself to account for these disturbances is naturally, that they were caused by the ejection of the traps through the already formed sandstones. In answer to this it may be said that it is very difficult to see how just such a disturbance as this could have been caused in this way, the sandstones presenting no appearance of baking or other indication of heat, but seeming rather to have been *crushed* by a pressure from the south. Next the trap it is crushed to a confused mass, a little further a few layers of sandstone become distinguishable, still further these are all distinct but broken and pitching in every direction, and finally they grade into regular unbroken horizontal layers. It may also be said that the proofs already given of the greater age of the copper bearing rocks, as compared with the horizontal sandstones are so strong as to necessitate some explanation of these disturbances other than the one just mentioned. The only one that I can offer, is this ; the traps being deep seated are, as it were, independent of the more superficial sandstones, and would, if impelled to move by any force, move independently of them. Now a very slight movement of the traps northward against the sandstones would produce all the phenomena observed. Such a movement is not at all difficult to explain." (See also Am. Jour. Sci., 1874, (3) VIII., pp. 46–56.)

In 1879 Professor Irving adopted, in part, a different mode of explaining the phenomena observed above. He remarks :—

"It appears that at the contact there is in many cases a confused brecciated mass of sandstone and crystalline-rock fragments, some of which are of great size, while in places they become rounded, and the rock passes into the ordinary conglomerate. These peculiar appearances, only in one case reaching to any considerable distance from the crystalline rocks, are to be attributed in the first place to the naturally confused mode of deposition on the cliffy shore of the waters in which the sandstones were originally deposited, but, as I have shown in another place, a slight movement northward of the deep-seated crystalline rocks against the more superficial sandstone would account for much. Another thing tending to confuse would undoubtedly be the chemical action, which, as is well known, is so apt to be set up with unusual energy along the contact of dissimilar formations." (Geol. of Wisc., 1880, III., pp. 17, 307.)

Mr. E. T. Sweet, in his report in the same volume, (p. 337, see also pp. 349, 350,) states in regard to the same phenomena, that "on Middle river, the original lines of deposition have been entirely obliterated, and the very argillaceous sandstone transformed into a transverse cleaving slate, somewhat micaceous." This shows the incorrectness of Professor Irving's statement that the sandstones present "no appearance of baking or other indication of heat." It seems to us that the phenomena observed can best be explained by supposing that dikes intruded themselves after the sandstone was in position, and it is surprising that observations of a more thorough nature were not made so that the question should have been settled. The fracturing, the upward bending of the layers of sandstone, its induration and metamorphism, are all ordinary occurrences in the contact of intrusive matter with the adjacent rock, and other explanations should not be resorted to until rendered necessary by the facts observed. No such phenomena have been observed in the contact of the Azoic with the Palæozoic rocks in the vicinity of the Great Lakes. In fact, it seems from Professor Irving's own language that he would hardly have adopted the explanation he did, if Messrs. Pumpelly and Brooks had not previously endeavored to sustain the view that the copper-bearing rocks are older than the Potsdam sandstone.

Again, it is not shown that these traps are of the same age as those of Keweenaw Point. The only evidence advanced would be quite as effective to show that many of the dikes in the granites and schists of the Azoic, or even the traps of Nova Scotia, are Keweenawan. Moreover, if a lateral thrust is necessary to explain certain facts seen, the phenomena observed could be as well accounted for in this way on the supposition that the sandstone was traversed by a dike, as by the hypothesis that it was a newer formation abutting against the Cupriferous series.

In another place Professor Irving states : —

> "Fortunately, however, we have at hand a more absolute proof than this, of the age of the Keweenawan System, for at the Dalles of the St. Croix river, thirty miles above its junction with the Mississippi, and on the west line of Wisconsin, we find horizontal sandstones and shales, crowded with characteristic Primordial fossils, lying upon the irregular and eroded surface of a Keweenawan melaphyr. The contact is finely exposed, and the sandstone near the junction is full of rounded and angular fragments of the underlying melaphyr. This place was described by Owen, but, so infected was he with the prevalent ideas of intrusive rocks, that he looked upon the melaphyr as the newer of the two, disregarding the overwhelming evidence of direct superposition, of the undisturbed condition of the sandstone, and of the melaphyr pebbles and boulders it contains. . . . . It is evident enough, then, that we have here proof absolute that the Keweenawan series belongs below the base of the Palæozoic column of the Mississippi." (Geol. of Wisc., 1880, III., pp. 23, 24, 339, 396, 397, 423 ; Trans. Wisc. Acad., 1875–76, III., pp. 45–52 ; Owen, Geol. Survey of Wisc., Iowa, and Minn., pp. 164, 165.)

In Prof. T. C. Chamberlin's Report, prepared from the notes of the late Moses Strong, it is stated of the same locality : —

> "This locality presents the most clear and unequivocal evidence that the Copper-bearing series is much older than the Potsdam sandstone of our state, so much older, indeed, that there was time for the very extensive wearing down of the former before the latter was deposited." (Geol. of Wisc., 1880, III., pp. 416-419.)

Professor Irving later carried his work into the Michigan region, and thus states the conclusions at which he arrived : —

> "The series is older than the Cambrian and younger than the Huronian — the separation from the former being by an intervening disturbance and erosion, and from the latter by an intervening erosion, and possibly also by an intervening folding and alteration."

He further found the acidic rocks, from which most of the Keweenaw conglomerates were derived, in place, and adopted the published view of Dr. Wadsworth (*ante*, pp. 113-122), that these rocks are old rhyolites and trachytes. (Report of the Director of the United States Geological Survey [2d Annual], 1882, pp. xxxi.-xxxiv.) Irving also adopted the theory of a synclinal structure of the region, first announced by Foster and Whitney.

Mr. A. R. Selwyn later claimed that he had not expressed any opinion regarding the age of the trap and sandstone of Lake Superior, forgetting the previous expression of his views that they were Huronian (see *ante*, pp. 106, 108), but gives as the result of his studies in 1882 the view that

> "they occupy the geological interval elsewhere filled by those divisions of the great lower paleozoic system which underlie the Trenton group. Various considerations point to the Potsdam and Primordial Silurian (Lower Cambrian) as their nearest equivalents. . . . They are essentially volcanic, sub-aerial, and sub-aqueous formations, and in every sense analogous to the wide-spread tertiary volcanic rocks of Australia and other regions. The only differences are their greater antiquity and the consequent greater changes and modifications they have undergone through the operation of long-continued metamorphic agencies, disturbance, and denudation ; though these changes are far less than those which rocks of the same age, and to some extent similar origin, have undergone in eastern America and in Britain." (Science, 1883, I., pp. 11, 221.)

It is obvious that these views are identical with those published by Foster and Whitney in 1850. (*Ante*, pp. 76-131 ; see also Science, 1883, I., p. 39.)

Professor Irving in reply to Mr. Selwyn stated that "the copper-bearing rocks underlie unconformably — and with an immense unconformity — a series of sandstones holding Cambrian fossils." He further remarked "that the copper-bearing strata also underlie unconformably the eastern sandstone of the south shore of the eastern half of Lake Superior." He also complains that the evidence of himself, Sweet, and Chamberlin regarding the Taylor's Falls locality had been ignored by others. (Science, 1883, I., pp. 140, 141, 359, 360, 422.)

It was in reply immediately pointed out by Dr. Wadsworth, that the above-mentioned observations had neither been ignored nor denied; but that the trouble was that the Wisconsin geologists themselves had ignored the simplest principles of the geology of eruptive rocks, which they themselves admit these to be. (Science, 1883, I., pp. 248, 249.)

In the mean while Dr. Hunt stated that the

> "view of the continuity of the cupriferous series with the Potsdam (St. Mary) sandstone was maintained by Whitney; but Logan, in 1863, put forth strong, and to most minds conclusive, reasons for believing that the highly inclined cupriferous rocks at the east end of the lake pass unconformably below this sandstone." (Science, 1883, I., pp. 218, 219.)

It was then pointed out by Dr. Wadsworth, that

> "the evidence advanced by Logan, which Dr. Hunt finds so convincing, was mainly a difference in dip between the traps and sandstones at localities several miles apart; and that all the evidences, as Logan himself says, only '*seem to support the suspicion* that the sandstones *may* overlie unconformably those rocks, which, associated with the trap, constitute the copper-bearing series.'" (Science, 1883, I., p. 307.)

Prof. N. H. Winchell then, in agreement with Foster and Whitney, and with Selwyn, remarked with reference to the statements of the latter: —

> "I concur with him in the sweeping affirmation, 'that there is, at present, no evidence whatever of their [the cupriferous rocks] holding any other place in the geological series' than that of the 'Potsdam and primordial Silurian'; and I would also add, that there is much incontestible evidence that they *can hold no other*." (Science, 1883, I., p. 334.)

Later, Prof. T. C. Chamberlin summed up the various reasons for supposing that the Keweenaw rocks were distinct from the adjacent sandstones. They were: the different stratigraphical relations; differences in thickness and in constitution; unconformity; the inherent consistency of this view; the dynamic simplicity of this view; and the discovery by the United States geologists of a like series in the Grand Cañon of the Colorado. He in no wise meets the direct evidence previously given, that the sandstone and traps are one and the same formation, while his arguments ignore the mode of formation, i. e. they would be of value only if both the eastern sandstone and the copper-bearing rocks were of exclusively sedimentary origin. (Science, I., pp. 453–455.)

Since so much has been claimed for the Taylor's Falls locality, it will be necessary to pay some attention to the connection of this with the known copper-bearing rocks of Michigan. Beginning at the Nemakagon district, some granites and diabases are found on opposite sides of the Nemakagon River. A thousand feet below is more diabase. About 250 yards south is a small exposure; then, about 100 yards west, another. Four miles northeast is to be found a series of diabase ledges extending for a quarter of a mile. About twelve miles northwest of this is a belt

> "nearly thirty miles in length, over which are scattered, in comparative profusion bare or slightly concealed ledges. . . . . With two exceptions — viz., a sandstone and a conglomerate — the series is formed of trappean rock, mainly diabase and diabase-amygdaloid."

After passing over an intervening space of about thirty-six miles, diabase and quartz porphyry were met with in the Clam Falls district. From this locality on there is a series of outcrops varying from one fourth of a mile to about five miles apart, extending to the Taylor's Falls region (St. Croix district). (Geol. Wisc., 1880, III., pp. 399–415.)

We see then that these rocks, according to the testimony of the Wisconsin geologists, have been mainly determined on lithological evidence, and that when any outcrop of a diabase or melaphyr was found it was placed without question in the Keweenawan series. Again, these outcrops are widely separated by drift-covered regions, and thus far the Wisconsin geologists have not advanced the slightest proof that the St. Croix diabase is the same as the Michigan lava flows.

Dr. Owen stated in regard to this locality, that the trap had

> "forced its way through highly fossiliferous strata, breaking up the beds immediately overlying it, entangling and partially indurating the fragments, without, however, tilting or metamorphosing the adjacent beds in any perceptible degree. The fossils, even of the beds almost in contact with the trap dykes, are in a perfect state of preservation, and the strata themselves have no dip perceptible to the unassisted eye in the hillside where they are exposed." (Geol. Surv. Wisc., Iowa, and Minn., 1850, pp. 164, 165.)

In a foot-note Dr. Owen also states that the remains of the shells can be "detected in fragments enclosed in the trap, and so much altered as to be distinguished with difficulty from the surrounding greenstone." It seems hardly possible that Owen could have made these statements if part of the trap at least was not intrusive in the sandstone.

Mr. J. H. Kloos (Zeits. Deutsch. Geol. Gesells., 1871, XXIII., pp. 417–448; Geol. Minn., 10th Ann. Report, for 1881, pp. 175–200) states that he found the sandstone horizontally overlying the trap, or diabase as we — in agreement with Rosenbusch — should prefer to call it. He also observed a conglomerate made up of the ruins of the diabase; but the relations of the conglomerate to the sandstone were not ascertained.

Prof. N. H. Winchell claims that the sandstone in this locality is not the Potsdam, but belongs to a higher formation. This view he holds on account of the physical characters of the rock, as well as differences in the fossils it contains. (Geol. Minn., 1st Ann. Report, pp. 68–80.) Later, Professor Winchell considered the St. Croix sandstone as belonging to the Quebec group, and as overlying the Potsdam sandstone, to which latter he referred the copper-bearing rocks of Keweenaw Point. (Geol. Minn., 10th Ann. Report, pp. 123–136.)

From what has been given it can readily be seen that Messrs. Irving and Chamberlin have failed to recognize the simplest features of the geology of mixed eruptive and sedimentary rocks; and that the conditions upon which they place so much reliance to prove the correctness of their views are exactly those which occur (excepting the presence of fossils) whenever a sandstone or conglomerate is found intercalated in the copper-bearing series. If their evidence is good, then we have "proof absolute" that the Keweenawan series — the copper-bearing rocks — is composed of as many distinct geological formations as there are beds of sandstone and conglomerate intercalated in them. So far as their yet published work goes, all their evidence has not advanced one step beyond that which was made known thirty-three years ago, and it is strictly in accord with the views of Foster and Whitney as then stated. Were this not the case, there is as yet not the slightest published evidence that the St. Croix traps belong to the copper-bearing series: they may be older or younger, while considerable evidence is given by Professor Winchell to show that the sandstone there is more recent than the Potsdam. Moreover, there is positive evidence that the copper-bearing rocks are part of the Eastern sandstone formation on Keweenaw Point. It seems, then, that the Keweenawan series owes its origin and perpetuity in part to erroneous observations, and in part to erroneous deductions from correct observations.

Prof. N. H. Winchell, in his Report for 1881, gives a summary of the geological opinions held regarding the copper-bearing rocks, which summary he appears to have made up with additions, but without acknowledgment, from that previously given by Dr. Wadsworth (*ante*, pp. 107–109), using also the more complete exposition of views presented on pp. 76–107. For an authoritative expression of Dr. Wadsworth's views he does not refer to this work (pp. 1–157), which was at that time in his hands, but to a brief abstract only. (Proc. Amer. Assoc. Adv. Sci., 1880, XXIX., pp. 429, 430.)

In the article previously referred to (this Bulletin, pp. 1–76), it was claimed by Dr. Wadsworth as the result of an examination of the literature relating to the Azoic region of Michigan, together with a considerable amount of study both in the field and in the laboratory with the aid of the microscope, that, in accordance with the early published views of Foster and Whitney, the granite was eruptive, as were the greenstones (diabase, melaphyr, etc.), part of the iron ore and jaspilite, the peridotite, etc.; and that these eruptive rocks, united with the sedimentary ones, made up the Azoic system; while there was no evidence existing to show that this formation could be separated into two divisions. It was pointed out that, in the subsequent Survey of the Lake Superior region by Messrs. Brooks and Pumpelly, great ignorance of the simplest principles of geology and lithology had been displayed, and that no confidence could be placed in the results at which they professed to have arrived.*

We now pass to the consideration of some later publications relating to the Azoic rocks of Michigan.

In 1881, the fourth volume of the Report of the Michigan Geological Survey, by Dr. C. Rominger, was published. The author of this Report appears to have known nothing of the work of others, excepting that of

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* It might further have been shown that, although Major Brooks professed in his Report to give a history of the scientific exploration of the Iron District of Lake Superior, he entirely ignored the work of Messrs. Foster and Whitney, by whom that region was first geologically mapped, and the important localities of iron ore laid down. It might also have been shown that the geological map of the Lake Superior region published by Messrs. Brooks and Pumpelly was, to a considerable extent, a copy of that of Foster and Whitney, and that not the slightest acknowledgment was made for thus incorporating into their own work the geology of extensive areas which had never been examined with any detail either by themselves or by their assistants.

Mr. T. B. Brooks; consequently numerous statements are put forth by him as original, when in fact they had been previously published by others. Had Dr. Rominger been more conversant with the literature of the district, many errors into which he has fallen would have been spared him, since he is essentially a palæontologist. However, he appears to have worked conscientiously, and to have endeavored to ascertain the truth so far as he could.

Regarding the so-called Laurentian granites, Dr. Rominger states: —

> "According to my own observations the granites of Marquette are eruptive masses which came to the surface after the Huronian beds were already formed, and by their eruption caused, not only the great dislocations of the Huronian formation, but the half molten plastic granite masses induced by their contact with the Huronian rock-beds, also their alteration into a more or less perfect crystalline condition, and commingled with them so as to make it an embarrassing task to find a line of demarcation between the intrusive and the intruded rock-masses." (*l. c.*, p. 6.)

He also points to the fact that lamination is no proof of stratification, stating that he had "in several instances seen narrow intrusive granitic dyke-masses similarly laminated by the parallel arrangement of the mica scales in them." (*l. c.*, p. 16.)

Dr. Rominger further proceeds: —

> "The granites, considered in their present surface position, are, in relation to the stratified sedimentary rocks of the Huronian series, actually the younger rock, so far as the intrusion of very large masses of granite between the stratified sediments can be demonstrated by clearly observable facts, and as the other larger bodies of granite inclosing them [the so-called Huronian schists] from two sides are in direct continuity with the vein granites, and lithologically identical with them." (*l. c.*, p. 22.)

While Dr. Rominger regarded part of the basic rocks as truly eruptive in the form of dikes and lava flows, he recognized also the intrusive nature of much of the remainder; but being unable, from lack of lithological training, to distinguish between the older eruptives and their associated schistose rocks, he — like Mr. Brooks — confounded them together, and adopted for explanation the following theory, difficult of comprehension, and certainly not at all consonant with the facts observed in the district, the difficulty lying with the observers, and not with the rocks: —

> "From such a standpoint, the various crystalline hornblende rocks found in association with the granites could be considered as remelted, completely metamorphosed, Huronian sediments, on account of their nearest proximity to

the volcanic focus, while those more remote from it did not altogether lose their sedimentary structure, but still became altered, and frequently streams of the lower melted or emolliated plastic masses broke through them, filling transverse ruptures or entering between the ledges parallel with the bedding." (*l. c.*, p. 23.)

The rocks thus united Dr. Rominger classed as the "Dioritic Group." He showed, as Dr. Wadsworth had already done, the incorrectness of Major Brooks's work, and how little reliance could be placed on his conclusions.

Dr. Rominger appears to have found in the Menominee iron region a condition of things very similar to that existing in the Marquette district, and arrived at similar conclusions. (*l. c.*, pp. 240, 241.) His idea that the Marquette and Menominee schists are Huronian means nothing beyond this, that they appear to him to be lithologically similar to the rocks called Huronian in Canada; while — so far as his actual work goes — he reaches conclusions regarding the relation of the granitic and schistose rocks identical with those advocated by Foster and Whitney thirty years before. The result of Rominger's work is decidedly opposed to the division of the Michigan Azoic into two or more formations.

The question of the origin of the iron ores was not only discussed in the previous portion of this Bulletin, but also elsewhere. (Proc. Bost. Soc. Nat. Hist., 1880, XX., pp. 470–479.) The following indorsement of these views, with permission to publish it, was received from Mr. A. R. C. Selwyn: —

"I believe with you that many of our great Archean iron-ore beds are of eruptive origin, while others are stratified iron-sandstones, analogous to those which are now forming along the northern coasts of the St. Lawrence Gulf by the combined action of the rivers and the waves on the more ancient (probably eruptive) ore beds. But such magnetic ores always contain from 40 to 50 per cent of insoluble matter (probably chiefly silica), a much larger proportion than those which are presumably of eruptive origin."

Professor Dana, in opposition to the view of the eruptive origin of the iron ore and jaspilite, claims that conformability is the evidence used principally in deciding that the ores and schists are alike in their mode of origin. He also attempts to decide the point by appeals to other regions. It seems to us that the origin in each region is to be proved by the study of the district itself, and that arguments from analogy when used alone are fatally defective.

The question of conformability was the one examined, and upon which the decision regarding the origin of the iron ore was made. A careful examination of the literature showed that there was no published evidence of more than a superficial study of the relations of the ore to the associated schists; but all was based on theoretical views. Now the examination described previously was made for the express purpose of determining the relations of the ores and schists, without regard to any one's views. It showed that — wherever their relations could be determined — they were those of an eruptive rock in contact with a sedimentary one. These things were described and figured, and no one has yet attempted to meet the evidence, either to deny it or explain it away.

Two other attempts to discredit this view, besides that of Dana, were made. One was by Prof. J. S. Newberry, who, being evidently unable to meet the evidence given, contented himself by remarking that "to be asked to believe that the ore sheets are intrusive is a greater strain upon my credulity than it can endure." In other words, he takes especial pains to show that scientific questions are with him merely a matter of theoretic belief, and not one of evidence and facts. ("The Genesis of our Iron Ores," School of Mines Quarterly, Nov., 1880, p. 8.)

The second attempt was made by Dr. A. A. Julien, who likewise ignored the evidence, and confined himself to saying, "The mineralogical constitution and infusibility of these ores, their distinctly sedimentary lamination, etc., clearly testify to the unsoundness of these hypotheses." (Proc. Phila. Acad. Nat. Sci., 1883, pp. 335–346; Trans. N. Y. Acad. Sci., 1882, II., pp. 6–8, 13–17.) If these ores are regarded as an extrusion from the molten interior of the earth, their mineralogical constitution and infusibility have no bearing upon the question; but, on the other hand, if they are of sedimentary origin Dr. Julien must explain how it was that later they became plastic, so as to become intrusive, as they plainly are. That they are distinctly sedimentary in their lamination, or that the jaspilite is a fine silicious sand, we deny. Messrs. Julien and Newberry both show in their writings that they have not made themselves acquainted with the mode of occurrence of the Marquette iron ore, either by observations in the field, or by study of the published descriptions. Dr. Julien's paper is especially replete with errors.

Passing now to the Azoic rocks of Wisconsin we find that in 1876 Mr. E. T. Sweet pointed out a supposed unconformability between the Laurentian and Huronian at Penokee Gap, stating (Trans. Wisc. Acad., 1875–76, III., pp. 43–44): —

> "When the railroad cut is completed at this locality, the absolute junction of Laurentian and overlying Huronian will doubtless be exposed. There can

be no doubt of the unconformability of these formations, approaching each other as they do with a persistent opposite dip and somewhat different strike. Unconformability has been shown to exist between the Laurentian and Huronian in Michigan, but this is the first time it has been proven in Wisconsin."

Of the same supposed unconformability at Penokee Gap, Prof. R. D. Irving remarks (Am. Jour. Sci., 1877, (3) XIII., p. 308): —

> "The crystalline rocks of Wisconsin include unquestionably two distinct terraces, the one lying unconformably upon the other, as is beautifully shown at Penokee Gap, on Bad river, in the Lake Superior country. Here a white siliceous marble of the Huronian, overlaid by hundreds of feet of distinctly bedded slaty rocks, and dipping northward, is to be seen within twenty feet of large ledges of dark colored amphibolic gneiss, whose bedding planes dip southward and strike in a direction diagonally across that of the more northern beds. There are no doubt instances where the two series are difficult to separate, similar rocks occurring in both groups, but the existence of the two is incontestable."

In the third volume of the Geology of Wisconsin (pp. 94, 98, 108 116, 117, 248–250) accounts of the unconformability of the Laurentian and Huronian are given, but the kind of contact when seen was not observed. But if the Laurentian rocks are eruptive, then of course there would be unconformability. The proof advanced was, that the foliation of the granite and gneiss dipped at a different angle from that of the Huronian rocks. Here, as in the case of the Keeweenaw series, the Wisconsin geologists failed to take into account the conditions necessary to prove their points; while Professor Irving, without giving any evidence of value, made out a beautiful fault — on paper — at the Penokee Gap. So far as can be judged from the evidence presented by these geologists, it appears that they have in Wisconsin the same structure as exists in the Azoic of Michigan, namely, a series of mixed sedimentary and eruptive rocks.

From the following extracts it will be readily seen that there are no other than lithological grounds for assigning these rocks to the Huronian and Laurentian: that they are two distinct formations they entirely fail to prove.

Major T. B. Brooks states (Geol. of Wisc., 1880, III., p. 468): —

> "No rocks affording to me the slightest suggestion of a conglomeritic structure have been found in the Laurentian system, its rocks being always highly metamorphosed, and often so much so as to destroy all traces or suggestions of bedding."

In the same report (p. 531) Mr. Brooks also points out several areas of granite in which this rock was found to be intruded into the supposed

Huronian. There seems not the slightest reason to regard this as anything different from the so-called Laurentian granite, and this strengthens the probability of the view that the so-called Laurentian granite is really eruptive in the so-called Huronian. (*Ante*, pp. 22, 70, 71.)

In 1880, Professor Irving gives as the reasons for assigning the rocks which are placed in the Laurentian in Wisconsin to that system, their

> "close lithological similarity — the only marked difference being the absence of crystalline limestones in the Wisconsin area — of similar structural relations to the Huronian, Keweenawan, and Lower Silurian systems, and of probable direct continuity with the Canada Laurentian through the upper peninsula of Michigan and underneath the waters of Lake Superior." (Trans. Am. Inst. Min. Eng., 1880, VIII., pp. 480, 481.)

Of the Huronian in the same article it is stated (p. 483): —

> "The rocks of this series have been called Huronian by Brooks, and, in the writer's judgment, correctly so, on account of their similarity to the Canada Huronian, with which they not improbably have a direct connection underneath the Silurian of the eastern part of the peninsula, but more especially because they evidently occupy the same geological interval as the typical Canadian series, exhibiting the same non-conformity with an underlying gneissic and granitic system."

It appears, then, that the only evidence that the Wisconsin geologists have that the Laurentian and Huronian are what they purport to be is lithological; and they have advanced no sound argument showing that they form distinct ages in the Azoic System. The relation of the two supposed series is not that which is seen when the Palæozoic comes in contact with the Azoic, or what it would be naturally were the Huronian laid down on the pre-existing Laurentian. The contacts — when these contacts have been figured — appear rather to be those made by eruptive rocks with prior existing ones. The geologists before mentioned have assumed, not proved, the sedimentary metamorphic origin of all the rocks in question, and on the correctness of that assumption depends their argument. They have failed to observe the phenomena of the contact, when seen, beyond the mere fact of a different dip to the foliation observed. In fact, they have failed to prove any of the points essential to establishing their conclusions.

Later, Irving advanced, as if original with himself, the view that the so-called greenstones or diorites of the Marquette district were eruptive, and that the hornblende was secondary after augite. This too when the portion of this Bulletin relating to the Iron and Copper districts of Lake Superior (*ante*, pp. 1–157) had been sent him, in 1880, at his own special request. Although professing to indicate the microscopic work which had been previously done, he ignores completely that given in the pages before mentioned, which anticipated him in almost every point. (Am. Jour. Sci., 1883, (3) XXVI., pp. 27–32, 155.)

In 1866 Prof. James Hall referred some gneiss and granite on the Redwood River to the Laurentian, and some quartzites in the valley of the Minnesota River to the Huronian. This was done solely on lithological grounds, while the two series of rocks were not seen together. (Trans. Am. Phil. Soc., 1869, (2) XIII., pp. 329–340.)

It would seem that Dr. F. V. Hayden held that the quartzite was most probably supra-Carboniferous, Triassic, or possibly Cretaceous. This was on account of fossils which were found in some quartzite in the adjacent region. (Am. Jour. Sci., 1867, (2) XLIII., pp. 15–22). Part of Professor Hall's views were regarded as untenable by Prof. N. H. Winchell. (Bull. Minn. Acad. Sci., 1874, pp. 100, 101.)

In 1872 Prof. N. H. Winchell divided the "granitic and metamorphic rocks" extending across Minnesota from the northeast to the southwest into Laurentian and Huronian; on what grounds does not appear. (Report on the Geological Survey of Minnesota, 1872, pp. 64–67.)

In 1880, in the Report of the Geological Survey for 1879 (p. 26), Professor Winchell remarks: —

> "We hence see the Potsdam in its extension to Duluth involved with these igneous rocks, in upheaval and metamorphism, and cannot resist the conviction that the whole series known as the Upper Copper Bearing Rocks, or as the Keeweenian, or as the Quebec Group, on different authorities, was correctly assigned to the Potsdam at first by Messrs. Foster, Whitney and Hall in 1849, and subsequently by D. D. Owen."

The evidence on which he relies in making this statement is the fact that the copper-bearing rocks at Duluth are seen to be continuous with, and to form part and parcel of, the Potsdam sandstone as it extends from that point into Wisconsin. This view of Professor Winchell's harmonizes with that which has already been shown by us to exist in Michigan. The Minnesota geologists have not furnished any evidence, other than that based on lithological resemblances, to uphold the division of the Azoic system into the two series Huronian and Laurentian. Moreover, it seems to be the fact that in this State, as well as in Michigan, the supposed Keweenawan is nothing more than Potsdam.

THE FORTIETH PARALLEL SURVEY.

The results of the Fortieth Parallel Survey, in so far as the geological and lithological investigations are concerned, will be chiefly found in the first, second, third, and sixth volumes of the series of publications of that Survey. These volumes will be referred to in the following pages simply as I., II., III., and VI.

The first of these, in the order of publication, is Volume III. This bears the title of "Mining Industry," and is chiefly devoted to practical matters connected with mining and metallurgy. It is therefore of minor importance to us in connection with our present inquiry.

The second in order is that of Professor Zirkel, Volume VI., bearing the date of 1876. This volume is devoted to setting forth the results of a microscopical examination of the lithological collections of the Survey. The next is Volume II., containing the descriptive geology, by Messrs. Emmons and A. Hague. This volume comprises the whole geological work of the Survey, discussed in a geographical order. It bears the date of 1877 on the title-page. Volume I., by Mr. King, entitled "Systematic Geology," was issued last of all, in 1878. It contains, as its title imports, a systematic discussion of all the geological, lithological, and chemical investigations of the Survey, treated in chronological order, or in that of the geological age of the formations. In the present necessarily brief examination of that part of the work of the Fortieth Parallel Survey which is connected with the subject of the present paper, the relation between Volumes I. and II. should be borne in mind, and will be best understood on reading the following statement by Mr. King:—

> "The purpose of this volume [I.] is to present, as briefly as possible, a systematic statement of the data collected, and the induction we have been able to make. In Volume II. will be found a continuous description of the geological facts observed, treated geographically. . . . . *Whoever wishes to know the structure and details of given features should consult that volume.*"

In the first place it will be noticed that Mr. King begins his volume with the consideration of what he calls the "Archæan." Nothing being said in the way of defining what is meant by this term, it would naturally be supposed that it was employed with the same meaning as that intended by Professor Dana,* by whom the name Archæan was introduced into geology as the equivalent of the Azoic of Foster and Whitney. By them this latter term was used to designate the rocks which had assumed their present position prior to the deposition of the lowest member of the Lower Silurian.* Thus, for instance, in accordance with this view, granite erupted after the Jurassic epoch could not be called Archæan. It does not appear, however, that Mr. King had this idea clearly present in his mind while writing the volume in portions; at least, this is the result to which an examination of the work leads us. In fact, at the beginning of the chapter headed "Archæan," he says: —

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* See, in reference to this point, farther on, page 547.

> "At intervals over the whole mountainous area west of the 100th meridian, masses of gneiss or crystalline schists, with their associated marbles, dolomites, and quartzites, and eruptive bodies of granite, porphyries, gabbros, &c., are found to underlie more recent strata."

The rocks here mentioned he then immediately proceeds to designate as "these Archæan bodies," without any limitation as to their geological age.

In order, therefore, that we may ascertain how far there is evidence justifying the calling of these various "bodies" Archæan, according to the original geological meaning of that term, it is desirable that we should take up some of the more important regions where this "Archæan" occurs, and examine briefly the evidence by which its geological age has been established.

The first supposed Azoic (Archæan) rocks with which we have to do are those of the Colorado (Laramie) Range. The rocks of this range are granites and gneisses, with a very little mica schist (I., p. 22). It is evident that Messrs. King, Emmons, and Hague in general regard as a gneiss any granitoid rock which possesses in the slightest degree a parallel arrangement of its constituent minerals. It is also evident that in most cases they call this condition stratification.

Regarding this range we find no proof advanced that the granites and gneisses are stratified, and not eruptive, except the foliation above mentioned. Since it may be claimed by some that Professor Zirkel by his microscopic observations proved these and other granites to be of metamorphic sedimentary origin, it is perhaps well to look at his evidence. He distinctly states (VI., p. 59) that the diagnostic characters that he has given as distinguishing metamorphic, older eruptive, and younger eruptive granites from one another, "are valid only for the examined rocks of the Fortieth Parallel, and that it is not allowable to generalize from them for other countries." From this it is evident that these

* See Dana's Manual of Geology, 2d ed., 1875, p. 148.

characteristics were not the result of any previous study, but solely of the investigation of these particular rocks. Since Professor Zirkel never studied the rocks of the Fortieth Parallel Survey in the field, and since these diagnostic characters were obtained from those rocks only, how was it possible for him to know which were metamorphic, which older eruptive, and which younger eruptive granites?

Mr. King states that the supposed Archæan rocks were proved to be of that age, not only by their lithological characters, but also by their being seen in contact with the Potsdam and some presumably Cambrian rocks. These contacts were not within the limits of the Fortieth Parallel Survey, and he gives us no information in regard to their characters. (I., p. 21.)

Mr. Hague's statement, however, goes to show that in point of fact these rocks were upheaved in some parts since the Triassic; in others, since the Jurassic; and in others, since the Cretaceous (II., pp. 6–93). This demands that one of two theories should be adopted; either that these rocks were pushed up in a solid body, or that they were eruptive. In the former case, they are regarded as ancient land bodies, about which the later formations were deposited, all being subsequently uplifted by the granite upthrust. We fail to find any evidence in the publications of the Survey that examinations were made to see if the later formations (except the Tertiary and Cretaceous) contained *débris* from the supposed Azoic (Archæan); or to ascertain whether the contacts were those of one rock laid down upon another, or eruptive, or such as would naturally occur in case a solid mass was thrust up through another. In fact, no evidence in regard to these points is adduced, except the statement that the supposed later formations lie unconformably against the Archæan, which unconformability would exist in any of the before-mentioned cases. Had evidence been seen, we cannot imagine it would have been passed over in silence. So far as this district is concerned, the oldest rocks in contact with the granitic rocks are of Carboniferous age. The supposed Azoic rocks are considered to be Laurentian on the strength of lithological resemblances, and they are also said to constitute one formation. In the district in question, however, it is impossible to prove them to be older than the Carboniferous; and by neglecting to give the evidence, if any existed, they are not shown to be older than the beginning of the Cretaceous. (I., p. 299.)

The gabbro of this range, which, according to Dr. Hunt, has the characters of the Norian (Proc. Bost. Soc. Nat. Hist., 1878, XIX., p. 276), Mr. King says is eruptive through the granites (I., p. 27), while Mr. Hague makes the same statement (II., p. 13). If this gabbro is Norian, and Mr. King is correct in stating it to be eruptive through the Laurentian granites, it follows that the Norian formation is older than the Laurentian; or else that the supposed Laurentian granites are not of that age, — that is, if we are to accept the theories of Dr. Hunt and some of his followers: he, however, holds that the granite (gneiss) of the Colorado Range is Laurentian. (*l. c.*, p. 276.)

The Medicine Bow Range is referred by Mr. Hague, "with considerable hesitation," to the Huronian, and this reference is said to be "based entirely upon lithological evidences." Part of the rocks are sedimentary; but a large portion regarded by Messrs. King and Hague as sedimentary has not been proved by them to be so. The question still remains, therefore, How much of the supposed Huronian characters is due to eruptive agencies and their concomitants, and how much to geological age? The evidence advanced by Mr. Hague shows that the upheaval of the range was not completed until at least as late as the Cretaceous epoch, while, in fact, no proof is given that it is older than Tertiary. It was seen in contact with no rocks known to be older than the Triassic, although beds supposed to be of Carboniferous age were observed in one locality. The kind of contact formed by these Huronian rocks with the supposed later ones was not noted; neither do we have any information given that *débris* from the Huronian were found in the other formations, until high up in the Tertiary. Had such *débris* been observed it unquestionably would have been mentioned, since not only here, but in the Colorado Range, the occurrence of such material is noticed in the Tertiary.

The supposed Huronian formation has not then been proved to be older than the beginning of the Tertiary, and in the present state of geological science it is impossible, if the age of the other formations has been correctly determined, to prove it older than the Carboniferous. We do not find any evidence given that the uplift of the Park Range took place prior to the Cretaceous; there being here the same absence of proof as was indicated in the case of the two preceding ranges. In this case, however, no rocks older than the Triassic were found in contact with the supposed Archæan, and yet the range — on lithological grounds, purely — is assigned to the Laurentian. The evidence in regard to Rawling's Butte seems to be the same as that relating to the Park Range, through the Archæan schists of which Mr. Emmons remarks that basalt is seen to have been erupted.

The next series of supposed Archæan rocks is in the Uinta Range. The rocks there, according to Mr. King, are quartzites and hornblendic and hydro-mica schists. Another quartzite unconformably overlying it, and said to contain fragments of the Archæan (I., p. 154), is referred with doubt to the Carboniferous. In some places the Archæan gives evidence of having been uplifted since the Fox Hill Cretaceous (II., p. 268). Mr. Emmons, it seems, would refer these rocks to the Huronian on account of their lithological characters.

The Wahsatch Range was regarded as the type of the Archæan (Azoic) exposures in the district covered by Mr. King's survey. It is, however, more difficult to make out from the writings of Mr. King and his coadjutors what they believe its history to have been, than it is to learn their ideas of any of the other districts within their field of exploration. It would also seem that in some places their views regarding the origin of the granites, and the geology of the Wahsatch Range, in general, had decidedly changed during the time which elapsed between the publication of Volumes VI. and I.; Volume II. representing the later transition period, with a still greater change since Volume III. was published. In order to give some idea of the views of Messrs. King, Emmons, and Hague, it is necessary to quote to some extent from their writings, as well as from Volume VI.

At the time of the publication of Volume III. (1870), it seems Mr. King held that the granites were all of eruptive origin, and of Jurassic age; while the stratified rocks in his district were regarded as conformable from "the early Azoic up to the late Jurassic period." In that volume Mr. King says (III., pp. 2, 3) of the region covered by his Survey: —

> "The greater part of the rock is a series of conformable stratified beds, reaching from the early Azoic up to the late Jurassic period, when these level beds were compressed into vast mountain corrugations and elevated above the sea in a general, wide, and high plateau. Accompanying the upheaval and crumpling of this great oceanic family, and bursting from its fractured folds, are important masses of granite, penetrating the axes of the flexures and breaking through lateral fissures. Quartz-porphyries, felsite rocks, and notably syenitic granite, with occasional occurrences of granulite and greisen, accompany the ejections of granite. The date of their orographical period is assigned to the late Jurassic on grounds which will be found fully discussed in the first volume of the present series. . . . This Exploration has demonstrated that all the parallel ranges of the Great Basin, including the chain of the Wahsatch, its eastern wall, belong to the same system [Jurassic] of upheaval."

Not only were the grounds on which the Jurassic age was assigned to the granite not subsequently discussed, but in point of fact an entire change of view took place previous to the publication of Volume I., the reason for this absolute reversal of opinion in regard to a fundamental point in the geology of the Cordilleras being nowhere given, and — what is still more inexplicable — no allusion being made to it.

Mr. Emmons, in describing part of the same range (the Wahsatch), states (II., pp. 355, 360–363, 365): —

> "A body of Archæan slates and granite is surrounded, and partly covered, on all sides except the west, by a conformable series of sedimentary rocks, of an aggregate thickness of over 30,000 feet, extending in age from the Cambrian to the Jurassic inclusive. The granite mass, though eruptive, has not been protruded through this immense thickness of overlying rocks, but their beds were deposited around and over a submerged mountain-range of granite surrounded by Archæan rocks; and subsequent elevation, flexure, dislocation, and erosion have produced the conditions represented on the map, where it will be seen that of this conformable series, now bent and twisted, different horizons from the Cambrian up to the Middle Coal Measures are at different points in contact with the granite body. Of the immense arch which once covered this body, the western half has been faulted down, while the top of the arch, with its thickness of 30,000 feet of rock masses, has been broken up and worn away by atmospheric agencies. . . . . In Big Cottonwood Cañon, ... is a small exposure of granite. . . . . It is difficult to say whether this rock should be considered as part of the main granite body, which it does not resemble very closely, or with the later outbursts of granite-porphyries and diorites, which are found intersecting the sedimentary rocks of this region. These dikes of porphyry and diorite are very frequent, especially around the Clayton Peak mass and in the region where the mineralization of the beds has been most developed. . . . . Near this granite or diorite body of Big Cottonwood Cañon, in one of the beds of the upper part of the Wahsatch limestone, is a dike about 20 feet wide, of syenitic granite-porphyry, so classed by Zirkel, which resembles the granite in general appearance. . . . .
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> "The Palæozoic beds of this region, which fold around and partly cover the granite body, have been subjected to intense compression and local metamorphism, twisted and contorted in every direction, faulted and dislocated, and penetrated by intrusive dikes and mineral veins . . . The great belt of Wahsatch limestone, which forms the main stratigraphical landmark in these formations, ... forms massive cliffs at the southern head of Little Cottonwood, and here already, in the mantling of white, through its general blue color, shows the commencement of the metamorphism which has marbleized its beds in great degree from here to the mouth of Mill Creek Cañon, where they disappear beneath the Salt Lake plain. This belt includes, as has already been stated, the three groups of Lower Coal-Measures, Sub-Carbon-

iferous, and Nevada Devonian. . . . . Between Little Cottonwood and American Fork . . . . all these beds standing at high and varying angles, and being much broken and contorted."

In Volume I. Mr. King remarks (pp. 44–48) : —

" The Archæan rocks in the explored portions of the Wahsatch are exposed at intervals along the west front of the range for nearly 100 miles, and are composed of granites, garnet rocks, aplitic schists, and a very extended series of gneisses and hornblendic schists, with subordinate quartzites. The manner of their exposure is of very great interest, involving the most extensive dynamic action observed within the limits of the Fortieth Parallel Exploration. The chain of out-crops clearly represents an old Archæan range of bold configuration, which has been buried beneath an enormous accumulation of Palæozoic and Mesozoic sediments. It was this buried Archæan range which controlled the position and direction of the modern Wahsatch Range. After the uplifts took place, and the Palæozoic and Mesozoic strata were thrown into their present inclined position, a great longitudinal fault occurred throughout this whole portion of the range, by which the entire western half of the ridge was thrown downward from 3,000 to 40,000 feet, and is now entirely buried beneath the Pliocene and Quarternary formations of the Salt Lake basin. The present abrupt west front of the Wahsatch is the standing face of this great fault, and here the Archæan rocks are seen to occupy the core of the range, unconformably underlying the Palæozoic series, and rising to different stratigraphical horizons in the overlying series. In the southern portions of Map III., in the region of Cottonwood and Little Cottonwood cañons, is exposed an approximately conformable series of 30,000 feet of Palæozoic strata, overlying the granite and schists which there together form a portion of the early Archæan surface. The origin and nature of the granites at this point are obscure. There seem to be two distinct types — a granitoid gneiss, having a decided stratification, and an apparently eruptive body, which possesses in an interesting degree the conoidal structure so prominently developed in the granites of the Sierra Nevada. About fifteen miles south of Salt Lake City the Palæozoic beds are thrown into a broad semicircular curve, having a convexity to the east and a varying dip always away from the centre of this curvature. The ends of the strata of this great flexure advance westward until they approach the region of the great fault, their eroded edges forming the foot-hills of the range. The centre and nucleus of this immense curvature is a body of Archæan rock, composed partly of schists, but principally of a great central mass of granite and granitoid gneiss, having its best exposures in Little Cottonwood Cañon and the peaks to the south, and again in the Clayton's Peak mass, where it rises like an island through the strata of the Lower Coal Measure limestone and the Weber quartzite. . . . . Although in Clayton's Peak, and again near the lower end of Little Cottonwood Cañon, the rock possesses all the physical habit of a truly eruptive granite, and although in the Clayton's Peak region the granite has undoubtedly been a centre of local metamorphism and of metalization, yet, from the position of the overlying strata, a preponderance of evidence points to the belief that, whether eruptive or not, it is still of Archæan origin; hence its relations with the later stratified series are only those of rigid underlying masses, and the local metamorphism observed in the limestones near the granites is strictly mechanical, and not to be mistaken for the caustic phenomena of a chemically energetic intrusion. It should be mentioned, however, that it possesses, both in its interior composition and in a peculiar conoidal structure, close affinities with the unmistakably eruptive granites of the Sierra Nevada; and it is quite possible that subsequent study will determine the presence here of two distinct granites, the one having a regular bedding and belonging to the stratified Archæan series, the other of conoidal structure and eruptive origin. The main body extends about twelve miles northeasterly, from the trachyte slopes of the Traverse Hills to the head of the Little Cottonwood Cañon. Its greatest north-and-south expansion is through Lone Peak, a line about eight miles long. South of the mouth of Cottonwood Cañon a narrow isolated patch of granite appears involved in the Archæan schists. . . . . Passing up Cottonwood Cañon, no sharp line of division between the structureless granite and the bedded gneissoid form is observable; but there appear gradually more and more planes having an easterly dip, until finally they approach the regularity of gneiss bed-planes, and the minerals are seen to possess a vague general parallel arrangement. . . . . The mineralogical differences through all these bodies of granite are indeed slight; changes of texture and arrangement produce a decidedly varying petrological effect, but in general they are granites, containing — besides the normal orthoclase, quartz, and biotite — plagioclase, hornblende, titanite, and apatite in high proportion; all but the apatite being visible to the naked eye. . . . . There are present in this neighborhood, then, two distinct families of rocks: first the Archæan, consisting of schists and granite; second, the vast, conformable post-Archæan group of sediments. Wherever observed, the region of contact between the two families displays no marked metamorphism on the part of the sedimentary series, and within the Archæan series no such transitions as would lead to the belief that the granite is only a more highly metamorphic form of the crystalline sedimentary series; on the contrary, the contact is so clearly defined, and the rocks are mineralogically so dissimilar, that it is very evident that the granite is either an intrusive mass or else an original boss over which the Archæan sedimentary materials were deposited. While the granite itself bears a very close resemblance to the Californian eruptive granites, its relation to the flexed Palæozoic strata would indicate that they were bent around a solid body, not that a plastic granite intruded into the bent Palæozoics. The absence of granite dikes penetrating the immense sedimentary series would strengthen the belief that the granite antedated it. It is also noticeable that the dip and strike of the Archæan schists west of the granite body are entirely discordant with the overlying Cambrian series, the former striking northeast and dipping northwest, the latter striking northwest and dipping southeast, this unconformability being preserved up to the contact. Supposing the whole Archæan body to have been thrust upward and eastward when the flexure of the Palæozoic series took place, the present dip of the Archæan schists and quartzites would indicate that before the great Wahsatch uplift they were in a nearly vertical position, flanked to the east by the granite mass."

We may now investigate a little more in detail the question of the nature and origin of the granite, as well as the theories put forth by Messrs. King and Emmons, to account for the stratigraphical position of the rocks of the Wahsatch Range. In examining further we find that Mr. King divides the eruptive granites of his survey into four types (I., p. 107), and remarks: —

> "This classification, based upon field observations, is interestingly carried out by Zirkel, whose microscopic examinations in every way confirm the field arrangement." (I., p. 109.)

Of these types the Wahsatch granite is taken as the youngest; but he says: —

> "There is absolutely no evidence whatever in favor of the belief of granitic extrusions later than the Archæan age. . . . . As an instance of how dangerous any attempt to correlate age by petrological features alone really is, may be cited the Jurassic granite of California and the granite of the Cottonwood region on the Wahsatch, which is unmistakably Archæan. They are positively identical down to the minutest microscopical peculiarity." (I., p. 111.)

We now turn to the work of Professor Zirkel, whose manuscript was revised by Mr. King and his assistants previous to its publication. And since all his information in regard to the field relations of the rocks was obtained from them, we may assume that his statements give a fair idea of Mr. King's views at the time of its publication. He remarks: —

> "The decidedly eruptive granites may be divided into two classes: one embraces those older rocks that are of ante-Jurassic age; the other, those which have obtruded themselves through the Jurassic strata. For the enormous mass of eruptive granite of the Sierra Nevada, Professor Whitney has demonstrated a Jurassic origin; and, although not definitely proven, a similar age is assumed for a considerable class of granites along the Fortieth Parallel, whose petrographic constitution and habitus are identical with those of the Sierra Nevada. The full details of the reasons of this assignment will be found in the chapter upon granites in Vol. I. of this series. When, therefore, in this memoir, Jurassic granite is spoken of, the intention is to designate that family of which the Sierra Nevada occurrence is the type in age and constitution. . . . . Clarence King has long since shown that the eruptive Jurassic granites, and only these, are characterized by the presence of macroscopical titanite." (VI., pp. 39, 40.)

It has been seen that Mr. King divided the eruptive granites into four groups, a classification which, as he states, Professor Zirkel's "microscopic examinations every way confirm"; but, in point of fact, the latter divides them into two classes, the older eruptive granites containing no titanite, and the younger eruptive or Jurassic granites which are characterized by the presence of that mineral. (VI., pp. 58, 59.) The Wahsatch granite is regarded as the most characteristic type of the younger or Jurassic granites bearing titanite. (VI., pp. 50–52.) We have been unable to find in the writings of Messrs. King, Emmons, and Hague any statement why their ideas of the age of these granites underwent so radical a change after 1876, — any reference to new evidence discovered, or to the views previously held, — or how, in the light of what Professor Zirkel says in the chapter upon granite, he can be quoted as then sustaining Mr. King's views as published in 1878.

If Mr. King's ideas regarding the origin of the supposed Archæan are correct, thus far he has not been able to show that the rocks with which the Archæan is in contact are older than the Quebec group. In fact, he and his assistants have failed to bring forward any proof of value in support of their position. Rocks found in contact with others show by their relations, as a general rule, whether they (1.) were deposited against them as a sea-shore cliff; (2.) have been pressed against and through them as a solid mass; (3.) were chemically deposited in contact; (4.) came as intrusions, overflows, or in any other way. Each occurrence has its own individual characters. These characters, in the study of cases like the preceding, should be known from the examination of rocks whose origin and relations are known. We fail to find any evidence in their publications that Mr. King and his assistants looked for that proof which, if their views are correct, should exist in overwhelming abundance.

Where sedimentary rocks of Potsdam age have been deposited in contact with the Azoic rocks of Lake Superior, they show by the enclosed fragments that they were derived from the latter; they show, on examination of the contacts, that the Potsdam was deposited against a water-worn cliff; no sign of mechanical, eruptive, or any other force, except the impact of water, is to be observed. Had there been other forces acting to any amount along the contacts their effects would have been visible, and their history could be made out to a greater or less extent. So in the case of the Wahsatch Mountains, if the Palæozoic rocks were deposited against such cliffs as Mr. King imagines to have existed, the evidence to prove this should have been sought for. Abundant *débris* from the cliffs ought to have been found in the Palæozoic sediments. There cannot be a stratified deposit laid down upon a preexisting surface, conforming to its irregularities in such a manner as to present itself in the form of continuous layers. Yet Mr. Emmons describes such a phenomenon: hence the only conclusion following his views is that the solid granite slid up along the bottom of the quartzite, bending it so as to cause it to conform with the irregularities of the granite, and this elevation of the solid granite must have metamorphosed the limestone, and corrugated and uptilted all the adjacent formations; yet with all this the gentlemen studying the locality fail to show any evidence that the granite was solid at the time. Is it possible that an enormous mass of rough jagged granite could have been pushed like a huge rasp in contact with quartzites, limestones, etc., and have left no trace of its movement upon them? So, too, if it were intrusive, it should in like manner show by its contacts that such was the case. Instead of raising so extraordinary a fabric of theory on so slender a basis of facts, it would have been better to study the region a little more thoroughly. To us it appears highly probable that the granite was of eruptive origin, and of later than Archæan age. It is certain that the section of the Wahsatch Range given in the Atlas of the Fortieth Parallel Survey does not conform to the theories of Messrs. King and Emmons; and, moreover, that it represents impossible stratigraphical conditions.

Views very similar to those here expressed by the writers of this paper have already been published by Professor Geikie, Director of the Geological Survey of Great Britain, in an article having as its title, "On the Archæan Rocks of the Wahsatch Range" (Am. Jour. Sci., 1880, (3) XIX., pp. 363–367). From this paper the following extract is made, and it will be a sufficient indication of the light in which Mr. Geikie regards the geological speculations of Messrs. King and Emmons touching the structure and age of the range in question.

"According to the Reports of the Exploration of the 40th Parallel, the Wahsatch Mountains consist of a central core of Archæan rocks, composed partly of granites and partly of various quartzite, schists, and other crystalline masses. These rocks are represented as having formed an island in the Paleozoic sea; and Mr. King asserts that the island must have presented to the west an almost precipitous face of 30,000 feet, or upwards of 5½ miles — an altitude exceeding that of any mountain chain. Round this lofty Archæan island the whole of the Paleozoic and Mesozoic sediments are said to have been deposited to a depth of from 30,000 to 40,000 feet, in one continuous uninterrupted series. Subsequent terrestrial movements, acting along the line of the original island, have upraised the surrounding sedimentary masses, and the ancient crystalline rocks have once more been revealed by denudation. Now the fact of the existence of a cliff more than 5½ miles high would require to be established by very carefully collected and convincing evidence. It was with very considerable curiosity, therefore, that I paid a visit to the Cottonwood district, where the evidence was said to be most complete. I must frankly own that I failed to observe any grounds on which the assertion appeared to me to be warranted. One would naturally expect that if a mass of strata 30,000 feet thick had been laid down against a steep slope of land, its component beds ought to be full of fragments of that land. Each marginal belt, representing an old shore-line, should be more or less conglomeritic; at least, there ought to be occasional zones of conglomerate, just as at the present day, we have local gravel beaches on our shores. But I could find no trace of pebbles. It would of course be presumptuous in me to assert that they do not exist; but they are not mentioned by Mr. King, nor by Messrs. Hague and Emmons, and yet, as their evidence would be so important, we can hardly suppose that these writers observed them and made no reference to the fact. But not only have no pebbles of the Cottonwood granite been recorded as occurring in the overlying Paleozoic rocks, it is admitted that these rocks become metamorphosed as they approach the granite. The natural inference to be drawn from these facts, one might suppose, would be that the granite is later in date than the rocks overlying it. Mr. King admits that the granite has been undoubtedly the centre of local metamorphism, but this change he regards as 'strictly mechanical and not to be mistaken for the caustic phenomena of chemically energetic intrusion.' How he would discriminate between a mechanical and chemical cause producing precisely the same ultimate effect he does not explain. . . . .

"But if I am correct in regarding the Wahsatch granite as of post-Carboniferous date, then we are relieved from the uncomfortable incubus of these primeval mountains. We are not required to believe in the existence of a cliff 5½ miles high, which maintained its position and steepness during the greater part of all geological time. And we are spared the necessity of a colossal fracture of 30,000 feet on the west side of the Wahsatch Mountains."

We see no reason for proceeding further in the examination of the work of the Fortieth Parallel Survey. Enough has been said to give a sufficient idea of its character and value, as bearing on the question before us. In brief, the whole matter may be thus summed up: —

All the crystalline and the eruptive rocks, between the Wahsatch and the borders of California, with the exception of the modern volcanic ones, have been called by the geologists of this survey "Archæan." In not a single instance, so far as we are able to make out, has there been positive proof given that the rocks thus assigned were really of that age. In many cases the stratigraphical conditions are of a kind that such proof could not possibly have been obtained. In order to maintain the view of the Archæan age of the rocks in question in certain regions, the most extraordinary, and as it seems to us impossible, dynamic conditions have been invented, and sections drawn which are not consistent with the theories advanced, nor with the observations of Professor Geikie, nor with those of the senior author of the present paper. An attempt has been made to divide the granite into eruptive and metamorphic; and it is claimed that the division thus made in the field was supported by the independent microscopical examination of Professor Zirkel. In point of fact, however, it appears that the latter only observed certain differences between two sets of rocks submitted to him by the geologists of the Fortieth Parallel as having been determined, in the field, to be eruptive and metamorphic. These differences, however, are considered by Dr. Wadsworth to be non-essential, and not such as would, in the case of other specimens from other regions, justify the lithologist in assigning rocks so differentiated to different origins. Indeed, Professor Zirkel, as already stated,* admits this. Furthermore, it appears that at the close of the field-work the crystalline and granitic rocks of the ranges of the Great Basin west of the Wahsatch were considered by Mr. King as being of post-Jurassic age, in accordance with the observations and results of Professor Whitney and his assistants on the Geological Survey of California; but that some years later, at the time of the publication of the volume of Systematic Geology, these rocks were all classed as Archæan, without any reference to the fact that so radical a change of views on a point of so much importance had taken place, and with no sufficient evidence for its support. It needs hardly be added, that any reference to a division of the Archæan (Azoic) into sub-groups in the Fortieth Parallel reports can only be looked upon as wholly without importance or value, otherwise than as indicating certain mineralogical resemblances to rocks described as occurring in Canada and elsewhere.

HAYDEN'S SURVEY.

In 1868 Dr. F. V. Hayden remarked that the "metamorphic rocks" in the valley of the Chugwater (Wyoming) were probably of Laurentian age, but it is not stated upon what evidence this opinion was founded. (Report of Commissioner of the General Land Office, 1868, p. 232;

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* See *ante*, p. 500.

U. S. Geological Survey of the Territories, 1867, 1868, and 1869, [1873,] p. 79.)

In the Report of the U. S. Geological Survey of Colorado and New Mexico, 1869, (pp. 22, 73, 87,) and in the publication last mentioned above (pp. 122, 173, 187), Dr. Hayden presents a clear statement of his views regarding the supposed Laurentian rocks in the region examined by him. He gives, however, no evidence in support of these views. It is simply a profession of faith, in the following words: —

> "I have assumed the position that all the rocks of the West are, or were, stratified, and that where no lines of stratification can be seen, as in some of the massive granites, they have been obliterated by heat during their metamorphism. . . . . This iron occurs in the gneissoid rocks, or what is called the Laurentian group, to which group, I believe, all the gneissic and perhaps the entire mass of metamorphic rocks of the Rocky Mountain system belong. I have assumed the position, in all my investigations, that there are but two classes of changed rocks in the West, viz., igneous and metamorphic, and that the oldest granites which form the nuclei of the loftiest mountain ranges were once aqueous rocks, deposited in the same manner as the limestones or sandstones of our most modern formations. . . . . The gold and silver lodes of this Territory [Colorado], so far as they are observed, are entirely composed of the gneissic and granite rocks, possibly rocks of the age of the Laurentian series of Canada."

On the same page from which the last remark is copied, Dr. Hayden distinctly shows that he regards the foliation of gneissoid rocks as synonymous with bedding and stratification. Had all our geologists been as frank regarding the theoretical views upon which their work is based, it would be far easier to estimate the value of their observations.

In the Annual Report for 1870 the same view of the age of the rocks in the valley of the Chugwater was repeated. Of the rocks on the north side of the Uinta Range, near the head-waters of Bear River, Dr. Hayden remarks: —

> "In all this series of strata, from the red beds to the oldest quartzites, I was able to detect no unconformability. . . . . I am inclined to believe that the upper beds are Silurian, that they pass gradually down without any break in the sequence of time to rocks of Huronian age. The purplish quartzites are almost precisely like those which occur at the Sioux Falls in Dakota, and at the Pipestone quarry, in color and texture, which Professor Hall regards as Huronian age." (*l. c.*, pp. 14, 50.)

The above quartzite appears to be the Weber quartzite (Carboniferous) of the Fortieth Parallel Survey, and the Uinta sandstone (Devonian) of Major Powell (Systematic Geology, p. 152; Geology of the

Uinta Mountains, p. 70). Hence, as it appears, considerable difference of opinion exists as to its age. Mr. S. F. Emmons apparently inclined to regard it as Cambrian (Descriptive Geology, p. 199), while Professor Marsh and Dr. C. A. White thought it probable that it was Silurian (Am. Jour. Sci., 1871, (3) I., p. 193; Annual Report, 1876, p. 23). In his Annual Report for 1871, (p. 39,) Dr. Hayden remarked: —

> "The precious metals, as gold and silver, are found, so far as my observations have extended, entirely in the metamorphic rocks which hold a position below all groups of strata that we have been in the habit of regarding as Paleozoic. Whether they belong to the series denominated in Canada the Huronian or Laurentian, we have no data to decide positively; but inasmuch as they are all clearly stratified rocks, they are plainly of sedimentary origin."

In the Report for 1873, Dr. Hayden stated that

> "the underlying metamorphic rocks [near South Park] are made up in part of quartzitic sandstones, full of rounded pebbles of quartz, which would indicate that they might belong to the Laurentian series." (*l. c.*, p. 41.)

In the Report for 1874, (pp. 190, 191, 239,) Dr. F. M. Endlich held that the granite and other so-called metamorphic rocks were formed from the metamorphosis of the Silurian and Devonian rocks in the district studied by him.* These rocks appear to be the same as those called Archæan by the other members of the Survey. (See also Report for 1875, p. 113.)

In the Annual Report for 1875, Dr. A. C. Peale makes the following statement: —

> "Sufficient data have not yet been obtained to determine the exact age of the metamorphic series, although, as Marvine remarks of those farther east, [Annual Report, 1873, p. 139,] 'the prevalence of siliceous and granitic types recalls the descriptions of Laurentian areas.' In one place the schists are very distinctly stratified, consisting of dark micaceous schists, with seams of quartz and feldspar. These may be of Huronian age, although we cannot trace their relations to those of the other Archæan rocks, as they are exposed in an isolated area at the bottom of cañons distant from the other outcrops." (*l. c.*, p. 64.)

In the Annual Report for 1877, (p. 156,) Dr. F. M. Endlich, in a tabular view of the formations of the Sweetwater district, divides the Azoic rocks into three systems. The oldest of these, called Prozoic, consists of massive granite. The third, called Huronian, likewise consists of granites, less massive than those of the first system, and containing darker-colored micas. The intermediate system, to which the name of Laurentian is given, is said to be made up of schists "composed of quartz, feldspar, hornblende, and mica." This classification seems to be purely a mineralogical one, and not justified at all — in so far, at least, as the giving of the names Huronian and Laurentian is concerned — by anything observed in the field. Indeed, Dr. Endlich himself states that,

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* The area between the meridians of 107° and 108°, and the parallels of 37° 15′ and 38° 15′, at the head of the Rio Grande and the Rio Animas.

> "although special examinations were made to determine whether the different mineralogical constitution of the [metamorphic or Archæan] rocks remained constant within certain zones, no applicable data upon this point could be obtained. . . . . Within the main chain the stratoid segregation of the granites is not very completely carried out. . . . . It would require the most careful examinations, conducted on a liberal scale, as to time, to elicit evidence bearing upon the former condition of this metamorphic area." (*l. c.*, p. 66.)

Much the same may be said, with truth, of the division of the Azoic series into sub-systems by Dr. Hayden's assistants, Professor St. John and Dr. A. C. Peale. The former assigns the crystalline rocks of the Teton district to the Laurentian and Huronian systems, placing the granites and gneisses in one division, and the quartzites and slates in the other, there being no stratigraphical basis whatever indicated for this arrangement. The reference to the Huronian is, indeed, suggested only with doubt by Professor St. John. (*l. c.*, p. 480.) The same is true of the division of the Archæan into "Huronian?" and "granite," given by Dr. Peale. (*l. c.*, p. 612.)

It appears on examining the published volumes of the Hayden Survey, as well as from personal investigation of a part of Central Colorado by one of the authors of the present paper, that through the whole extent of the Cordilleras, and especially in the Rocky Mountain region proper, the axes of the mountain chains are usually made up of crystalline rocks, entirely destitute of fossils. These rocks are chiefly granites and gneissoid granites; slates occur in extremely subordinate quantity. In the northern portion of the chain, where the entire Palæozoic series, including the Potsdam sandstone, is developed, there could be no hesitation in assigning these *when not eruptive* to the Azoic or Archæan. But it is not certain that there is any Archæan proper in the whole range of the Cordilleras; and in most cases it is beyond doubt true that the axes of the chains have been erupted and the stratified masses uplifted at a period much later than the Azoic. Thus, for instance, we have in California post-Jurassic and post-Miocene eruptive granitic centres or axes, in the Sierra Nevada and Coast Ranges respectively.

Furthermore, in the Central and Southern Rocky Mountains we find that a large portion of the lower divisions of the series of stratified rocks is wanting. Thus in the Front Range of Colorado the crystalline masses are directly overlain by rocks generally admitted to be of Triassic age. In such cases, and in these regions, we have the same difficulties which occur in the Appalachian ranges; it is—or at least has been up to the present time—very difficult for most geologists to clearly distinguish, either in the field or in the cabinet, between metamorphic eruptive and metamorphic sedimentary rocks.

WHEELER'S SURVEY.

In the Reports of the Geographical and Geological Survey west of the one hundredth Meridian, under Capt. Geo. M. Wheeler, we have seen no evidence advanced to prove the occurrence in the supposed Azoic areas examined by that Survey of distinct geological formations.

Of the rocks called "Archæan" in the region explored in 1878 and 1879, embracing portions of North Central New Mexico and South Central Colorado, Professor Stevenson says:—

> "No absolute evidence exists to settle the age of these rocks. Lithologically they bear close resemblance to the Laurentian series of the east, and at more northern exposures within the Rocky Mountain region they have been referred by all observers to that age. The coarse gneissoid and often conglomerate granite immediately underlying the Carboniferous at many localities may possibly be of somewhat later origin." (Wheeler's Report, Vol. III., Supplement, p. 72.)

JONES'S SURVEY.

In a Report upon the Reconnoissance of Northwestern Wyoming by Capt. Wm. A. Jones, in 1873, Prof. Theo. B. Comstock remarked on the Azoic rocks examined by him:—

> "There are some slight reasons for placing a portion of the oldest of these rocks in a group nearly equivalent to the Laurentian system of the East, but it must be confessed that none of them are based upon much better foundation

than a certain similarity to that formation in lithological characteristics. Their position upon the stratigraphic chart is, therefore, entirely provisional." (*l. c.*, p. 106.)

POWELL'S SURVEY.

In the publications of the U. S. Geographical and Geological Survey, under Major J. W. Powell, we are able to find but little relating to the subdivision of the supposed Azoic rocks examined by that Survey.

In a "Report on the Geology and Resources of the Black Hills of Dakota," by Henry Newton and Walter P. Jenney, published in connection with Major Powell's Survey, and revised by Mr. G. K. Gilbert, the granite is shown to be eruptive along the foliation of the schist, and not a sedimentary rock. An attempt is made to divide the rocks of the region into two ages, Laurentian and Huronian ; but they do not appear lithologically to have the characters of either formation. The division into two groups is stated to be a lithological one only, as the two series conform in strike. A diversity of dip is said to have been observed at one point, but that observation is not insisted upon.

Furthermore, however, we find it stated that "the lithological evidence fails to give even its feeble support to the theory that the two Archæan groups of the Black Hills are the representatives of the two Archæan groups of Canada." (*l. c.*, pp. 45–80.)

CALIFORNIA.

The geological investigations of the California Survey, carried on from 1860 to 1874, show that the gold-bearing slates of the Sierra Nevada are of Jurassic and Triassic age. No fossils older than the Carboniferous have ever been found in that range. The Mesozoic series has been uplifted by eruptive granite, which forms the axis of the chain. On these uplifted rocks strata of the Cretaceous epoch rest unconformably and almost without disturbance. Hence it is a well-established fact — the geological age of the different formations having been made out by the discovery of fossils at numerous localities, and reference to their proper position by skilful palæontologists — that the upheaval of the Sierra Nevada took place between the Jurassic and Cretaceous epochs.

In like manner, the age of the strata making up the Coast Ranges of California has been shown, by discovery of fossils in numerous localities, to be Cretaceous and Tertiary. These strata have been uplifted at various times during the Tertiary epoch, in some regions even as late as the post-Pliocene.*

Of course, such being the case, there can be no rocks in California which can be properly said to belong to the Azoic system (Archæan).

In view of these facts, for the purpose of throwing further light on the methods and theories of Dr. Hunt, as set forth to some extent in the preceding pages, it will be well to quote some of the remarks published by him at various times in regard to the rocks of California.

In 1866 Dr. Hunt stated : —

> "The notion that gold belongs only to rocks of Lower Silurian age, was many years since disproved by its discovery in the Upper Silurian slates of eastern Canada, and more recently, it has been shown that the great gold mines of California are in strata far more recent, and chiefly of the Jurassic and Triassic periods." (Geol. of Canada, 1866, p. 196.)

In 1868 Dr. Hunt again states : —

> "The auriferous rocks of California belong to the Mesozoic period, being of Jurassic age." (Gold Region of Nova Scotia, 1868, p. 11.)

In 1877, however, Dr. Hunt visited California for the first time, and, having spent several days in the Sierra Nevada, published the following statement (Am. Assoc. Adv. Sci., 1877, XXVI., p. 266 ; Proc. Bost. Soc. Nat. Hist., 1878, XIX., pp. 276, 277 ; Macfarlane's "Geologist's Travelling Hand-Book," p. 13 ; Azoic Rocks, p. 244) : —

> "Eruptive granites are found in California, where they abound among the foot-hills of the Sierras, in Placer and Nevada counties. The crystalline schists observed by the speaker in these counties, and in Amador county, are Huronian, and have all the characters of the Huronian series as seen in the eastern regions of North America, and of the *pietri verdi* of the Alps. To this horizon are also to be referred the similar crystalline rocks of the Coast range of California, as seen near San Francisco and San Jose. The auriferous veins which, in the Rocky Mountains, intersect the Laurentian gneisses, are found

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* See Geology of California, Vol. I. *passim ;* and, for full information in regard to the geological age of the rocks of the gold-bearing belt, "The Auriferous Gravels of the Sierra Nevada of California," Contributions to American Geology, Vol. I. pp. 34–39.

in the Sierras alike in the Huronian schists and in the eruptive granites, which probably penetrate the Huronian series."

Dr. Hunt stated that the crystalline schists of the Sierra Nevada examined by him have "all the characters of the Huronian series as seen on the great lakes." (Proc. Bost. Soc. Nat. Hist., 1878, XIX., p. 276.)

In 1880 Dr. Hunt further stated that the gravel at the Blue Tent placer mine, in Nevada County, California, is "made up in great part of the débris of the crystalline Huronian schists of the region, including much greenstone or diorite rock." (Trans. Am. Inst. Min. Eng., 1880, VIII., p. 452.)

The present writers, having had occasion to make a prolonged and most careful examination of the rocks of the Sierra Nevada, and of the Coast Ranges of California, as well as of those of the south shore of Lake Superior, take occasion to remark, that no such resemblances as those pointed out by Dr. Hunt have any real existence. The rocks of the California Coast Ranges, even where most metamorphosed, differ, both microscopically and macroscopically, from those of the Sierra Nevada, and specimens from the two regions in question would never be mistaken for each other by any one having even a moderately well trained eye. In the same way, the slaty crystalline rocks of the Sierra Nevada differ nearly as much from those of the Azoic regions of Lakes Huron and Superior as do the basaltic lava-flows of the latter region from those of Mount Ætna. Macroscopically, the rocks of the two series could never be confounded with each other, and microscopically the differences are equally striking. Hence it appears that, while the palæontological evidence is entirely averse to the dicta of Dr. Hunt in reference to the Huronian age of the Coast Range and Sierra Nevada rocks, even the lithological characters are quite as little in harmony with his views. Recalling what Professor Dana has remarked in reference to the Lower Silurian age of Dr. Hunt's Vermont Huronian, it may here be added, that the latter has, by what he has published in regard to California, made out the Huronian to be also Mesozoic and Tertiary, so that this formation may be said now to represent, according to Dr. Hunt's views, the whole geological column from top to bottom.

PART II.

Résumé, and General Discussion.

The great length of the preceding division of this contribution to our knowledge of the older geological formations of the United States and the adjacent northern region makes it necessary for us to offer, in this second and concluding portion of our work, but a brief synopsis of the conclusions at which we have arrived in the study of these older rocks. We have already set forth, in considerable detail, the theories which American geologists have held at various times in regard to those older crystalline rocks to which the names Archæan and Azoic have been commonly applied, and in doing this we have had special reference to the necessity or possibility of dividing that series of rocks into two or more distinct groups. We have given the evidence on which these various theories were based with considerable detail, because the facts which developed themselves, as we pursued our inquiry, were so extraordinary that we felt it to be doubtful whether our statements would be accepted as truthful unless we presented the reader with the means of verifying them at once, on the spot, without the necessity of examining a long series of volumes, some of which are only to be obtained with the greatest difficulty. More work has, however, been done by us, both in the field and in the laboratory, in the investigation of the subject here discussed, than the cursory reader of the present article would perhaps be inclined to suppose; and we trust that the opportunity may yet be furnished us for carrying this work still farther in the same direction, and for presenting the whole body of the results which we have reached, as well as those which may hereafter be attained, in a fuller form than it is possible for us to do at the present time.

We think that it is impossible for any unprejudiced worker in this department of science to peruse with care the preceding pages, and not feel obliged to admit that the geology of a large portion of this country, and especially that of Canada and New England, is in an almost hopeless state of confusion. We think that it must have been made clear to the candid mind, that the geologist would find himself completely baffled who should endeavor to obtain any definite knowledge of the real nature and order of succession of the rocks which cover so large a portion of the region in question from the study of that which has been published with regard to them. We believe that we are justified in going still farther, and saying that our chances of our having at some future time a clear understanding of the geological structure of Northeastern North America would be decidedly improved if all that has been written about it were at once struck out of existence. That this condition of things is largely due to the erroneous observations and theories of the Canada Survey, which to a large extent have been adopted and blindly followed on this side of the Dominion boundary, is a statement the truth of which we think no one who has carefully studied the evidence presented in the preceding pages will not feel obliged to admit. While not desiring to conceal the fact that some of the problems presented in the course of the study of the older rocks are extremely difficult, we find it clearly proved that want of knowledge, want of experience, and a desire to produce sensational theories, have brought about this condition of confusion. Some of the salient points which have presented themselves in the course of this investigation into the history of geological opinion in this country will therefore now be passed in review, and the subject then left, for the present, to the reader's candid consideration.

The establishment of the Silurian System by Murchison opened the way to the discussion of the question whether the lowest limit of life in the geological series had been, or was likely to be reached. The fact that in England the lower fossiliferous rocks are greatly disturbed and metamorphosed, and that consequently their order of succession is very difficult to make out, rendered it much less easy to arrive at any definite conclusions in regard to this question than it was in countries like Bohemia and the United States, where the Silurian strata, over large areas, rest in undisturbed succession upon each other. Before, however, the investigations of Barrande had led him to infer that there was a distinct limit to traces of life in the descending order of formations, Murchison had arrived at this result, led thereto by his geological work in Scandinavia, which country he had visited in connection with his reconnaissance of European Russia, and where a large amount of detailed investigation of the lower rocks had already been made by the able Swedish geologists, all of which was placed at his disposition.

The first use of the term "Azoic," with an approach to a definite meaning, was made by Murchison, with reference to the rocks of Scandinavia. His statement was as follows: —

"On this point we have recently convinced ourselves, by clear and indisputable sections, that the lowest beds charged with anything like animals or vegetables are the exact equivalents of the Lower Silurian strata of the British Isles, and that these have been distinctly formed out of, and rest upon, slaty and other rocks which had undergone crystallization before their particles were ground up and cemented together to compose the earliest beds in which organic life is traceable. To the crystalline masses which preceded that palæozoic succession to which our researches were mostly directed, we apply the term 'Azoic,' not meaning thereby dogmatically to affirm, that nothing organic could have been in existence during those earliest deposits of sedimentary matter, but simply as expressing the fact, that in as far as human researches have reached, no vestiges of living things have been found in them, so also from their nature they seem to have been formed under such accompanying conditions of intense heat and fusion, that it is hopeless to expect to find in them traces of organization. . . . . In the term Azoic rocks, we include all the crystalline masses belonging to the ancient group of gneiss, together with ancient granitic and plutonic rocks by which they have been invaded." *

It will be noticed that Murchison considered that his "Azoic" rocks — in Scandinavia, at least — seemed to have originated under such conditions that the existence of organic life at the time of their formation was impossible; yet, as he hastens to add, he was not willing "dogmatically to affirm" that these rocks might not contain fossils. It is not easy to understand exactly what Murchison meant by these two evidently contradictory statements; but this want of tenacity of opinion in regard to the truly azoic character of the infra-Silurian rocks was still further exemplified in the various editions of his "Siluria," in the course of which we see the author passing gradually from an upholding of a series of necessarily non-fossiliferous "bottom rocks," up to a positive recognition of the Laurentian and Huronian systems of the Canada Survey, and the admission that the rocks designated as "Azoic" and said to be *necessarily azoic*, did furnish proofs of the existence of life on the globe at the time of their formation.†

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* Proc. Geol. Soc. London, Vol. IV. (1845), p. 602. The Geology of Russia in Europe, and the Ural Mountains, Vol. I. (1845), p. 10.

† In the first edition of "Siluria" (1854), the rocks called in "Russia and the Ural Mountains" Azoic are designated by the term "Bottom Rocks," and they are said to "lie below all those formations in which there are *the slightest vestiges of Silurian life.*" These rocks are also said to have been "formed, as I [Murchison] believe, at a period when the heat of the earth was antagonistic to the existence of living beings." In the third edition of the same work — the second is not at hand for reference — the Azoic rocks are designated as "primeval" and "fundamental," and it is said that "they *may* have been formed at a period when the heat of the earth was antagonistic to the existence of living beings." In the fourth edition of

Barrande, in his earliest communication embodying the results of his life-work among the Palæozoic rocks of Bohemia (1846), did not use the term "primordial," which he later adopted, and in which he included the lowest zone of life; but he speaks of his division "C" as "forming the base of the Protozoic rocks, according to the latest classification of the Rev. Professor Sedgwick." His (Barrande's) groups "A" and "B" constitute the "Lower Division," comprising all the Azoic formations, subdivided into two groups, their upper one ("B") being identified by him as the equivalent of Sedgwick's Cambrian, — the confusion in geological nomenclature caused by the introduction of this term having begun as far back as these earliest days of discussion in regard to the Azoic and Palæozoic rocks.

It appears, however, that Sedgwick, as late as 1854, had not arrived at any definite conclusions in regard to the existence of an Azoic series, for he says of his Cambrian, "that it seems to contain no organic remains." But he hastens to add, that the answer to the question when organic life began "is involved in inextricable obscurity." *

In 1851 † Messrs. Foster and Whitney made known the existence of a series of rocks on the south shore of Lake Superior, in regard to which they wrote as follows: —

> "Below all the fossiliferous groups of this [the Lake Superior] region, there is a class of rocks, consisting of various crystalline schists, beds of quartz, and saccharoidal marble, more or less metamorphosed, which we denominate the Azoic System. This term was first applied by Murchison and De Verneuil to designate those crystalline masses which preceded the Palæozoic strata. In it they include not only gneiss, but the granitic and plutonic rocks by which it has been invaded. We adopt the term, but limit its signification to those rocks which were detrital in their origin, and which were supposed to have been formed before the dawn of organized existence." ‡

It is now known that a large part of the vast region adjacent to Lake Superior on the north and east, and included within the limits of Canada and British North America in general, is occupied by rocks which by their infra-Silurian position and lithological character belong in the

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"Siluria" (1867), the Azoic is called "Laurentian," and is regarded as being "the base of all Palæozoic deposits."

* British Palæozoic Rocks and Fossils, 1854, Introduction, p. xxxii.

† A synopsis of their results had in the previous year (1850) been presented to the Department of the Interior, and in this the nature and geological position of the "Azoic System" had been clearly set forth. Senate Documents, 2d Sess. 31st Cong., 1850–51, II., Doc. 2, pp. 147–152.

‡ Foster and Whitney's Report on the Geology of the Lake Superior Land District, Vol. II. The Iron Region, together with the General Geology, 1851, p. 3.

Azoic of Foster and Whitney. These rocks had been met with by the geologists of the Canada Geological Survey, and were designated by them in the Report of Progress for 1845–46 as the "Metamorphic Series,"* their geological position not having been clearly ascertained, nor the question considered whether the lowest Lower Silurian really formed the base of the fossiliferous strata, so that rocks underlying them unconformably could properly be called Azoic.

After the publication of Foster and Whitney's Report — in 1854, namely — Mr. Logan, the chief of the Canada Survey, recognizing the fact that the term "metamorphic" had no special significance as designating the geological age of any group, since rocks in any part of the series may be metamorphic, adopted for the Azoic of Foster and Whitney the designation of "Laurentian," a name previously proposed by an eminent authority for a group at the other end of the geological series, and already in current use — an act of great injustice, as we have already pointed out.† Neither was any reference made in the report of the Canada Survey, in which the name "metamorphic" was exchanged for that of "Laurentian," to the fact that the geological position of these rocks had previously been definitely established, and another name given to them by the American geologists working on the southern side of Lake Superior.

Furthermore, owing to the inability of Mr. Logan to distinguish between the Azoic quartzites of Lake Huron, and the very dissimilar sandstones, conglomerates, and interbedded volcanic rocks of Keweenaw Point, utter confusion was introduced into the geology of the region of the Upper Great Lakes — in the minds, at least, of those accepting the dicta of the Canada Survey as authority — a condition of things which was not fully rectified until many years later. ‡

For some time after the introduction of the term "Azoic" into the geological nomenclature by Foster and Whitney, that term was current among geologists in this country. Dana, in the first edition of his "Manual of Geology," the Preface of which bears the date of November 1, 1862, and in the revised edition, issued in 1871, in which it is stated that the work "has received such alterations as seemed to be required by the results of recent geological research," adopts the term "Azoic," but not in the exact sense in which it was used by Foster and Whitney. He includes under that designation all the rocks which were in existence at the time animal life began, stating his views in the following words: "The Azoic rocks constitute the only universal formation. They cover the whole globe, and were the floor of the oceans and the rocks of all emerged land when animal life was first created. . . . . Whatever events occurred upon the globe from the era of the elevated temperature necessary to fusion, down to the time when the climate and waters had become fitted for animal life, are events in the *Azoic* age."

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* See *ante*, pp. 331 *et seq.*

† See *ante*, pp. 7, 338. Also, Am. Jour. Sci., (2), XXIII. 305–314; Proc. Bost. Soc. Nat. Hist., XXI. 121, 122.

‡ See a statement in reference to the results attained by the Geological Survey of Canada, published by A. R. C. Selwyn, present chief of that Survey, in "Science," number of February 9, 1883.

But farther on (*l. c.*, p. 145), Dana advocates the idea that there may have been life on the globe during the Azoic period, for he says, "The term 'Azoic,' as here used, implies absence of life, but not necessarily of the lowest grades." He then gives the following "reasons in favor of the existence of life of some kind [in the Azoic]." 1st. The formation of limestone strata. 2d. The occurrence of graphite in the limestone and other strata. 3d. The occurrence of anthracite in small pieces in the iron-bearing rocks of Arendal, Norway, which rocks are probably Azoic in age. He then proceeds to give reasons why, supposing the existence of life of some kind, it is more likely to have been vegetable than animal. But he distinctly admits (*l. c.*, p. 147) that "whenever the earliest plant, however minute, was created, then the grand idea of life first had expression, and a new line of progress in the earth's history was announced." And, still farther on (*l. c.*, p. 178), he admits that "*the life of the Potsdam period is the beginning of the system of life deciphered in American geological history.*"

In the second edition of his Manual, the Preface of which bears date March 1, 1874, Dana takes a position in reference to the Azoic system materially different from that previously occupied by him. He now introduces the term "Archæan," and defines "Archæan Time" as "the beginning, including a very long era without life, and finally that in which appeared the earliest and simplest forms of plants and animals." Farther on, however, (*l. c.*, p. 146,) he says, that "Archæan time includes strictly, as its commencement, an *Azoic* age, or the era in which the physical conditions were incompatible with the existence of life. *But this era, so far as now known, is without recognizable records;* for no rocks have yet been shown to be earlier in date than those which are now supposed to have been formed since the first life began to exist."

In view of the contradictions and confusion of ideas thus shown to prevail among the most eminent geologists in reference to the nomenclature of the oldest crystalline rocks, no one can do otherwise than admit that it is quite time that some more definite understanding should be had of this whole subject, and, as a contribution toward this desirable end the following remarks are submitted.

There are two essentially different ways of looking at the rocks which make up that portion of the earth which is accessible to investigation. One of these has reference to the manner in which these rocks have been formed; the other, to the chronological order in which they have come to occupy the position which they now hold. Roughly speaking, it is this idea which forms the basis of a division of the science of geology into two quite distinct departments, Dynamical and Historical Geology. For the study of the former a knowledge of lithology and petrology is indispensable, while the latter is chiefly an application of the results of palæontological investigation to questions of synchronism and order of succession in the rocky strata.

In considering other worlds than our own, no more important question could be asked in regard to them than this: Are they inhabited, or does organic life exist upon them? The only reason why this question is not oftener asked or more discussed is, that it is one to which a definite answer cannot now be given, while there seems to be extremely little chance that there will ever be any change in this respect. It is not beyond the bounds of possibility that some meteoric fragment may be dropped upon this earth bearing evidences of the existence of life on another world; but, up to the present time, the aspect of such bodies as have come to us from outside our own atmosphere has not been of a character to encourage any expectation that such an event may occur in the future. Still, it will hardly be denied by any one that proof of the existence of life on any of the planets, or any other of the heavenly bodies, would be accounted one of the most interesting revelations ever made to the human race. Similarly, to fix in the order of events through which this earth has passed the epoch when life began to exist on the globe, must be admitted to be a problem of high importance; and, as intimately connected with this, and of similar interest, would necessarily be the inquiry whether any rocks could be pointed out in regard to which it could be affirmed with truth that they were deposited, or brought into their present position, before the appearance of life on the earth.

Here, however, a point suggests itself as of importance in connection with the present inquiry; namely, that while there may be rocks which are azoic because no life existed when they were formed, there are others which from the very nature of their mode of formation and occurrence could not show any indication of the presence of life, even although it may have existed on the same planet, and in the immediate vicinity of the rocks in question at the time they were deposited or placed in their present position. Thus, no one would expect to find signs of life in lava, or in the granitic masses originally constituting a part of the earth's crust, and which were formed at a time when the temperature and other conditions could not have been favorable to the development of life, but which may have been raised since their formation into perhaps close proximity to strata replete with the remains of organized beings.

On looking over the subject of the existence of "Azoic" rocks — that is, of such formations as are destitute of evidences of the presence of life at the time of their formation or deposition — we find that there are several categories in which such rocks may be classed.

1st. We may have strata, once fossiliferous, in which the evidences of life have disappeared in consequence of the metamorphic changes which those rocks have undergone. Experience shows that such cases are not uncommon; but that, usually, the geological age of such metamorphic strata may be recognized, either by means of their position with reference to strata of known age, or by tracing the metamorphosed formation to such a distance from the source of the alteration in question that we find the formation manifesting itself in its original condition. To such metamorphic strata we should never have occasion to apply the term "Azoic," since we should clearly recognize the fact that their azoic character was something which did not originally belong to them.

2d. Rocks may be azoic, even if laid down when life was existing on the globe, provided the local conditions were not favorable to its development at the particular locality under consideration. Thus, much the larger portion of the Potsdam Sandstone of Lake Superior is entirely destitute of traces of life; yet, as there are occasionally — even if very rarely — localities where this rock is fossiliferous, we should not think of separating the fossiliferous portions from the non-fossiliferous, or of calling them by any special name, in consequence of the absence of traces of life in them.

3d. Again, rocks must necessarily be azoic, when formed or originating under such conditions as were incompatible with the existence of life.

The original crust of the earth must have been azoic, if we adopt the views held by the large majority of geologists, that our globe has cooled from a former condition of igneous fluidity. The volcanic and eruptive rocks must necessarily be azoic, because they have come from the heated interior of the globe, reaching the surface, for the most part, in a melted condition. We do not, however, designate the eruptive and volcanic rocks as "Azoic"; the fact that they are necessarily in this condition is assumed as something self-evident.

4th. We may have rocks formed under such conditions as were not inimical to life, but yet azoic, because life had not begun to exist on the globe at the time of their deposition. These, according to our view, would be the rocks properly designated by the term "Azoic," and the body of rocks having this character might properly be called the "Azoic System." And we think that, in view of what has here been set forth, no one will deny that it is important that, if there are such rocks, they should have a special designation, and that the term "Azoic" would be a proper one to apply to them.

This, however, is exactly what was done by Foster and Whitney, in 1850, when they gave the name of the "Azoic System" to a body of strata, originally — in part, at least — of sedimentary origin, which did not show by their character that life could not have existed at the time of their deposition, but which proved, on examination, to be entirely destitute of fossils, and which, moreover, were found everywhere to underlie unconformably other stratified formations which were recognized as containing the lowest known forms of organic life.

Over thirty years have elapsed since these rocks were designated as forming the Azoic System, and the point at present at issue is, whether anything has been discovered in geology which renders this designation improper, unnecessary, or undesirable, or which justifies the adoption of either one of the terms "Laurentian" or "Archæan," or both, the question of the propriety of dividing the Azoic System into two or more groups being one to be examined farther on.

The introduction of the name "Laurentian" by the geologists of the Canada Survey has been already commented on, and it has been shown that this term, as first used by Mr. Logan, was the exact equivalent of the Azoic of Foster and Whitney. That being the case, the question of the propriety of this action on the part of the author of the new designation may be left to the good sense of the reader, who will judge for himself whether replacing a designation already in use by another one, previously employed by another geologist with a totally different meaning, is a justifiable proceeding. And it will be noticed that any objection to the word Azoic, based on the ground that the formation in question had been found to contain organic remains, and therefore not to be properly called Azoic, was not in order at the time Mr. Logan introduced the term Laurentian, as it was not then pretended that these lower rocks were fossiliferous.

We proceed now to a discussion of the desirability of adopting the term Archæan, introduced by Dana; and, with this end in view, it will be necessary to look a little more minutely into the way in which it is used by this geologist. It will not have escaped the notice of the reader, however, that much in this discussion turns upon the question whether the so-called Azoic, Archæan, or Laurentian rocks are, or are not, destitute of traces of organic life. Hence, in order to clear the way for what is to follow, it will be well to take up this question at once.

To those familiar with the geological literature of the past twenty years, it will be evident that the only essential point before us is this: Is the *Eozoön* a "thing of life"? If it is not, then all the accessory evidence that the Archæan rocks are fossiliferous falls away of itself, as we shall endeavor to show, as being utterly intangible and unsatisfactory.

Without going into anything like a detailed account of the various publications issued by the Canada Survey, or under its inspiration, having it for their object to prove that there is a fossiliferous group of rocks below the lowest Lower Silurian (the Potsdam or Primordial), and of the discussion in regard to this point which has been going on during the past twenty years, we may content ourselves with giving a brief *résumé* of the facts connected with this rather remarkable chapter in the history of our geological progress.

Another name having been given by the Canada Survey to the rocks previously known as Azoic, it became desirable that the formation thus newly designated should be shown to be a fossiliferous one. For this purpose that problematical body now so well known under the name of the *Eozoön* was brought forward, and at the present time there exists quite a voluminous eozoönal literature.*

The first announcement in connection with the subject of the Eozoön was made by Mr. Logan, in his Report for the year 1858. In 1859 he exhibited specimens at the meeting of the American Association for the Advancement of Science, but went no farther at that time than to say that he was disposed to consider these specimens "as fossils." In 1864, Dr. Dawson, in his Address before the Natural History Society of Montreal, announced that he had "arrived at the conclusion that they [the fossils in question] are of animal nature, and belong to the very humblest type of animal existence known, that of the *Rhizopods.*" He adds, that "the discovery of this remarkable fossil, to be known as the *Eozoön Canadense*, will be one of the brightest gems in the scientific crown of the Geological Survey of Canada." *

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* For a chronological catalogue of this literature, see "An Old Chapter of the Geological Record," etc., by W. King and T. H. Rowney, London, 1881, pp. ix–liv.

This preliminary announcement was followed by several elaborate papers, by Messrs. Logan, Dawson, and Hunt, published in the Quarterly Journal of the Geological Society, as well as others by Dr. W. B. Carpenter, published in the Proceedings of the Royal Society, in which it was claimed that the fossil in question was a *Foraminifer;* or, to use Dr. Carpenter's exact words, "that the *Eozoön* finds its proper place in the Foraminiferal series, I conceive to be conclusively proved by its accordance with the great types of that series in all the essential characters of organization, — namely, the structure of the shell forming the proper wall of the chambers, in which it agrees precisely with *Nummulina* and its allies; the presence of an 'intermediate skeleton,' and an elaborate 'canal-system,' the disposition of which reminds us most of *Calcarina;* a mode of communication of the chambers when they are most completely separated, which has its exact parallel in *Cycloclypeus;* and an ordinary want of completeness of separation between the chambers, corresponding with that which is characteristic of *Carpenteria.*" †

From this time forward the Eozoön began to be an important matter. The authority of Dr. Carpenter, at first, bore down all opposition; and, with few exceptions, geologists and palæontologists gave this gigantic Foraminifer a place as the "earliest known representative on our planet of those wondrous powers of animal life which culminate and unite themselves with the spirit-world in man himself." ‡

Gradually, however, there came a reaction from the shock of this stupendous discovery, which first manifested itself in a denial, on the part of Professor Harkness (1865), of the organic nature of the Eozoön. This was followed in the succeeding year by an elaborate paper by Messrs. King and Rowney, in which they maintained that the *Eozoön Canadense* must be relegated to the inorganic kingdom. From this

* Canadian Naturalist, 1864, p. 220; Am. Jour. Sci., (2), XXXVII. 232.

† Quarterly Journal of the Geological Society of London, XXI. 64.

‡ Dawson, "The Dawn of Life," p. 1.

time forward, no year has failed to add something to the literature of this subject. But it must be admitted that the opponents of the organic character of the Eozoön have been on the whole decidedly in the minority. This problematical body has, almost without exception, gone into the various text-books of geology, in all countries where that branch of science is cultivated, with at most, in some instances, a vague intimation that there were some persons who were not disposed to accept the Eozoön as a relic of organized existence.

It was not an easy matter for those convinced that this body was simply a mineral to furnish satisfactory proof of the correctness of their opinion; for when it was said by them that they could discern nothing necessarily organic in the specimens of Eozoön which they had examined, it could always be replied, from the other side, that these opponents of the Eozoön had not had the opportunity of studying the series of specimens in the collections of the Canada Survey, and that these were so complete and convincing in character that every one to whom this privilege should be granted would be compelled to acknowledge that opposition to the views of Messrs. Dawson and Carpenter had no basis of fact.

In 1875, however, Professor Möbius of the University of Kiel, having discovered a Rhizopod, to which he gave the name of *Carpenteria Rhaphidodendron*, and which appeared to him, at first, to have an astonishing resemblance in its structure to that of the Eozoön, determined to make a thorough investigation of the Canadian supposed fossil, and, for this purpose, solicited material from all quarters. As he appeared to be, if not convinced, at least quite desirous of being convinced, of the organic nature of the Eozoön, he was supplied with all the best material in the hands of Dawson and Carpenter. Indeed, the latter, as Professor Möbius states, gave him one thin section, which he had never before allowed to go out of his hands, on account of its furnishing such important evidence of the organic nature of the Eozoön.*

The work in which the results obtained by Professor Möbius are given to the world is remarkable, especially, for the number and clearness of the illustrations which accompany the text, and they are of special value as allowing every one to see for himself just what the specimens amounted to, which were held by Carpenter and Dawson to furnish full evidence of the organic character of the Eozoön. The exact position of Professor Möbius when he began the investigation, and the result to which he attained, can be easily made out from the following sentence, in which the whole thing is summed up in a few words: "I began this investigation with the hope that I should succeed in proving, beyond possibility of doubt, that the Eozoön was organic. The facts, however, led me to the opposite conclusion."*

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* "Professor Carpenter hatte die grosse Güte, mir vortreffliche Präparate zu schicken; ja, er vertraute mir einen Dünnschliff zum Studium an, den er seines hohen beweisenden Werthes wegen noch niemals aus den Händen gegeben hatte." Möbius, in "Der Bau des Eozoon Canadense," etc., p. 177. In spite of this, we find Dawson claiming that the results obtained by Möbius should not be accepted as valid, because the latter "had access merely to a limited number of specimens." Am. Jour. Sci., (3), XVII. 197.

The value and importance of the investigations of Möbius have been acknowledged by Zittel, who thus expresses his opinion of the nature of the Eozoön: "In spite of the repeated answers of Dawson and Carpenter, this long struggle to maintain the organic nature of the Eozoön may well be admitted to have been brought to an end, and with a result unfavorable to that view, by the exhaustive memoir of Möbius." To this emphatic testimony on the part of Zittel may be added the equally positive statement, to the same effect, of the eminent palæontologist, F. Roemer, who thus states the case: "Finally, Möbius undertook an exhaustive microscopical investigation of this body [the Eozoön], in carrying on which he was able to make use of the best material in the possession both of Dawson and Carpenter, and he reached the positive and unquestionable result [sicheres unzweifelhaftes Ergebniss] that the supposed *Eozoön* is simply an inorganic formation [Bildung] consisting of serpentine and chrysotile in limestone. Consequently, by far the larger majority of geologists and palæontologists will consider this question as definitively settled, and will be *all the more ready to do so, since the occurrence of a fossil of this character in the oldest crystalline limestone was, on general principles, in the highest degree improbable.*"†

It is believed that in this country no geologist or palæontologist of eminence has distinctly put himself on record as being opposed to considering the Eozoön as a fossil. We have, however, a statement of Professor Leidy — a high authority on the lower forms of animal life, and who at the same time is familiar with minerals — to the effect that he, in 1877, "was not fully convinced of its [the Eozoön's] animal nature." ‡

Apart from the evidence so skilfully presented by Möbius, as well as by Carter, Rowney, and King, we have that of our own obtaining, and which we consider entirely decisive of the question, and in favor of the mineral nature of the Eozoön. The fact of the occurrence of the so-called "eozoönal structure" in some of the limestone deposits of Eastern Massachusetts has been repeatedly admitted both by the advocates and the opponents of the organic character of this peculiar body.* By most geologists these calcareous masses have been considered to be interbedded with and an original portion of the formation. and supposed to be beyond doubt of sedimentary origin.

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* *l. c.*, p. 189.

† F. Roemer, Lethæa Palæozoica, 1880, p. 285.

‡ Proceedings of the Academy of Natural Sciences of Philadelphia, 1877, p. 20.

In 1871, however, after a careful study of the eozoönal limestones of Chelmsford, Bolton, and Boxborough, Mr. L. S. Burbank claimed that these were not true stratified deposits laid down with the gneiss, but of subsequent formation to that rock, and of vein-like character; and that, in consequence of this, the Eozoön must be of mineral, and not of animal origin. These views were sustained by Messrs. W. H. Niles and J. B. Perry, — the latter extending his observations so as to include the locality at Newbury. Mr. Burbank gave figures illustrating the mode of occurrence of the limestone, and these seemed to furnish strong evidence in support of his views.†

Most of these localities have been studied by us, with especial reference to the origin and mode of occurrence of the calcareous material. At Stoneham, the limestone was found to occur in an indurated argillite, which is cut through by dikes of diabase (diorite), etc. The calcareous mass, lying approximately in the direction of the strike of the enclosing rock, frequently cuts across its lamination planes, so as to include masses of the argillite; and portions sometimes extend for a considerable distance across the stratification, so as to have the character of fissure veins. The limestone is entirely crystalline, and shows upon its borders that intense chemical action has there taken place, as it is greatly altered and filled with epidote and such other silicates as are ordinarily found resulting from conditions of the kind here suggested. While one of the dikes was seen to intersect the limestone, others were found to have been cut off by it. These latter dikes abutted directly against the limestone, and along the line of junction of the two rocks were the same evidences of intense chemical action which were seen at the edge of the calcareous mass in other places.

From this it follows that this limestone is a segregated or vein-like deposit, of earlier date than some of the dikes, but posterior to the time of the formation of the larger portion of them. It would seem from these observations that the calcareous mass was the result of the action of thermal waters during the time of the dying out of the volcanic forces which have been shown to have formerly been active in Eastern Massachusetts.*

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* See *ante*, pp. 411, 419.

† Proc. Bost. Soc. Nat. Hist., 1871, XIV., 189–204; Proc. Amer. Assoc. Adv. Sci., 1871, XX., 262–266, 270–276.

The limestone localities at Chelmsford, so fully described by Mr. Burbank, were also carefully examined by us. They are included in gneiss, and are extremely irregular, sometimes coinciding in direction with the lamination of the enclosing rock, and at other times cutting across it. So irregularly are the gneiss and limestone locked together that their relations to each other could, in our judgment, only be explained by admitting that the calcareous material is a segregated deposit. This "eozoönal" limestone is entirely crystalline, and filled with scapolite, actinolite, and other silicates; while the Eozoön is most abundant and best preserved in the most decidedly crystalline portions of the calcareous deposit. No dike was seen to be cut by the limestone; but one, of melaphyr, about two inches wide, was seen traversing it.

We have also studied the deposits of limestone in Newbury, known as the "Devil's Den" and "Devil's Basin." The relations of the calcareous mass to the enclosing rock at these localities are very similar to those already indicated for the others, and do not allow of explanation in any other way than by admitting that the limestone is a segregated deposit. The evidences of intense chemical action are here also plainly revealed by the presence, in the calcareous mass, of silicates, such as wollastonite and garnet. Moreover, the rock in which the limestone is enclosed — the country rock — is, as we think, an eruptive one, belonging with the older basalts, but of course much changed from its original character.

This view of the segregated nature of these deposits was, moreover, entirely freed from anything which it might have of a theoretical nature by our finding at Devil's Basin — the locality in which the Eozoön occurs — that the country rock was cut by dikes of eruptive rock, which squarely abutted against the limestone on the side without intersecting it. Also, the ends of the dikes next to the limestone showed the same intense chemical action and resulting secondary silicates that the country rock in like position does. All this indicates, in the most unmistakable manner, that the country rock was formed, and that dikes traversed it, *before the limestone was there.* In short, the calcareous mass has been introduced since the formation of the enclosing rock, and consequently could not by any possibility be an original contemporaneously bedded structure; neither could it be fossiliferous, any more than an ordinary veinstone could so be.

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* Harv. Univ. Bull., No. 22, pp. 359, 360.

For the purpose of accounting, to a certain extent, for the extraordinary delusion which has prevailed among palæontologists with reference to the organic character of the Eozoön, a few words may here be added. In the first place, attention may be called to the fact, that the discovery of traces of organic life in such rocks as lavas and granites, and even in slags and meteorites, has become one of the common occurrences of the present day. A long list of names might be cited of scientific observers who have enriched geological literature with "gems" of this kind. The reasons of this are in part to be found in the desire to do something sensational, and in part to the entire ignorance which prevails among many zoölogists and palæontologists as to the great variety of forms occurring in the mineral kingdom, which it only requires an imaginative temperament to endow with the attributes of organic structure. Symmetrical grouping of minute crystals, dendritic markings, radiated aggregations, fibrous structure, and many other commonly occurring forms in which minerals are found, have, each in turn, served as a basis for a new genus, family, or order in the animal or the vegetable kingdom.

A complete list of all the books and papers which have appeared within the past twenty or thirty years, — that is, during the latest epoch of geological enlightenment, — having for their object the display to the scientific world of dazzling "gems" of the Eozoön family, would form quite a lengthy document. Space can only be found for alluding to a few of these which are of special interest as bearing — more or less directly — on the Eozoön question, either as showing how the sponsors of this supposed organism have allowed themselves to be deceived in other and parallel cases, or how far, in general, those can go who have once taken up the idea that the peculiar mineral forms with which they are unfamiliar, and which have a superficial resemblance to the work of living organisms, are really such.

As Dr. W. B. Carpenter is the person who, more than any one else, is responsible for the generally prevailing belief in the organic nature of the Eozoön, it will be well to call attention, in the first place, to a communication of this eminent authority, published in "Nature," and headed "New Laurentian Fossil." In this he remarks, in reference to a specimen furnished him by a gentleman who had been "for some years on the outlook for fossils in the Laurentian rocks of Scotland," as follows: —

"The fabric seems to have consisted of superposed layers of calcareous shell substance, whose continuity is frequently interrupted. . . . . The state of preservation of the fossil thus corresponds exactly with that of the Silurian Stromatopora, to which, indeed, it bears a strong general resemblance. . . . . The shelly layers are as distinct in character from the calcite contents of the chambers, as are those of the Nummulites of the pyramid-limestone with which they agree in their remarkable hardness, corresponding with that of porcellanous shell. Altogether I have no hesitation in concurring with Prof. H. A. Nicholson, Prof. Geikie, and Mr. Etheridge in affirming it to be so unmistakably organic, that, if it be claimed by mineralogists as a 'rock structure,' a large number of universally-accepted fossils will have to go along with it. As it is *essentially calcareous* in its composition, there is no room for the hypothesis of its production by the process of 'mineral segregation,' which is maintained by certain mineralogists . . . . to have been adequate to the production of the alternating layers of serpentine and calcareous shell-substance in the Canadian *Eozoön.* And though mineralogical analysis might not improbably detect small particles of various minerals in its substance, their presence no more establishes its claim to be regarded as a mere rock structure, than does the presence of siliceous films . . . . in a piece of coral-limestone." *

Some weeks later Dr. Carpenter acknowledged that the fossil thus elaborately described by him was *not calcareous*, but that it consisted "of alternating layers of feldspar and quartz — the former simulating an organic structure like that of Stromatopora, and the latter occupying what had been supposed to be the cavities of that structure — *together constituting what is known to petrologists as 'graphic granite.'*" †

In this case, however, Dr. Carpenter might claim that, having made a mistake, he was ready and willing to withdraw his statements after he had been shown to be in error; and that, having done this, the value of his testimony in regard to the Eozoön was not thereby impaired. As an offset to this, we will proceed to show that in the case of one of the fundamentally important features of his supposed Foraminifer he was also as much mistaken as he was in regard to the graphic granite, and that he has admitted himself to be so; but that he did not make this admission until after having persisted in his error for many years, so that we are left entirely in the dark as to how long we must wait before being able to find out what his final opinion will be in a matter of this kind. The point is this: Dr. Carpenter, after having, at various times during an interval of fifteen years, called attention to the so-called "proper wall" or "nummuline layer" of the Eozoön, the existence of which he said that he had been able "*most satisfactorily to determine*," and which he considered to be "*a point of the highest importance in the determina-*

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* Nature, 1876, XIV. 9.

† Ibid., 68.

tion of the affinities of Eozoön," * has recently admitted that he was entirely mistaken in all this, and has conceded the fact claimed by the opponents of the organic character of this supposed fossil, that this nummuline layer was simply the mineral chrysotile in one of its ordinary forms of occurrence, namely, in bands or layers of finely fibrous material.†

In describing certain rocks of New Hampshire called by him "greenstones," and assigned to the Huronian formation by Prof. C. H. Hitchcock, Dr. Hawes made the following statements:—

> "In the microscopic study of these massive chloritic rocks, or metadiabase, I have found certain forms which appear to be of organic origin. . . . . It has the structure of a tabulated coral, resembling much a *Chætetes;* but on account of its minuteness, in connection with other characters, there is little question but that it is a fragment of a rhizopod mass or foraminifer;‡ and a close resemblance to a *Stromatopora* will be noticed. . . . . These forms seem to be abundant in the rock. . . . . The specimen figured is the most perfect that I have seen; but smaller fragments are abundant, and as they are apparently alike in dimensions, they sustain the supposition of the organic origin of all. . . . . These forms, distributed through the massive rock, have a structure, ... which cannot be attributed to crystallization. They seem to make it evident that rhizopods must have been living over the sea bottom during the accumulation of these sediments, and became buried in the mud which is now the material of the rock. These forms are composed of silicates. . . . . Yet upon placing a drop of acid upon one of them it effervesced for a short time, showing that carbonate of lime existed in it—perhaps part of that of the original foraminifer.
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> "The presence of these remains of rhizopods in the metadiabase is additional evidence of the sedimentary origin of these rocks; and they also confirm the view that the metamorphism was feeble in its degree, since it allowed of the preservation of these forms. . . . . Everything points to quiet waters during the original deposition,§ and finally to gentle metamorphism." ‖

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* Quart. Jour. Geol. Soc., XXI. 62.

† This retraction, on the part of Dr. Carpenter, of one of the most essential features of the Eozoön has not, so far as we know, been published; but it was made in public at a meeting of the Boston Natural History Society, and repeated in private at the Museum in Cambridge, in presence of one of the authors of this paper.

‡ The reader will be tempted, at this point, to exclaim with Dr. Carpenter, "Truly, as I have had occasion before to say, 'there is no limit to the possibilities of Foraminifera!'" (Nature, XIV. 9.)

§ It may be said that these rocks have been examined by Dr. Wadsworth, and their microscopic characters found to be identical with those of the altered diabases of Eastern Massachusetts, which occur in unmistakable dikes, cutting argillite (Primordial?). The field evidence, Mr. Huntington states, indicates that Hawes's rocks were in dikes.

‖ Am. Jour. Sci., 1876 (3), XII. 129–137.

The supposed fossils were examined by Principal J. W. Dawson, who pointed out their resemblance to parts of Hydroids, Bryozoans, Entomostracans, and some Devonian plants, or lastly to some supposed Laurentian fossils of Gümbel. He also says: "On the whole, though these objects are unlike any purely mineral substance with which I am acquainted, and are probably fragments of some organic body, I do not think it possible at present to indicate with any certainty their probable affinities." * These fossils also appear to have received Dr. Hunt's indorsement.†

Later, Dr. Hawes, having in the mean time studied in Europe, frankly acknowledged that his supposed fossils were simply the alteration products of titaniferous iron, stating: "The other gentlemen who have seen these specimens, and have published opinions in reference to them, are very excusable, on the ground that they [Dawson and Hunt] saw but single specimens, and are not professed experts in microscopic mineralogy. The author has paid some attention to the subject, under competent instruction, since the paper referred to was published." ‡

In view of what has been stated above, it would seem that Messrs. Dawson and Carpenter ought not again to claim to have any right to the expression of an opinion on points like those involved in the question of the organic character of the Eozoön, since they have both shown themselves entirely unacquainted with elementary mineralogy and lithology.

Of all the upholders of the organic nature of the Eozoön, there is no one whose work is so curious and instructive — from the point of view of one desirous of ascertaining how far the determination to find traces of life in everything can carry an observer — as is that of Otto Hahn. This author is an entire believer in the organic character of Eozoön; but is surprised that any one should be so blind as not to recognize that it is a plant.§ Fifteen different plant forms are described by him as made out from his Eozoön sections, and each is gifted with a distinct name. One animal appears to have had the exclusive range of this wonderful vegetation, the *Titanus Bismarki!* The title of the work in which all this is revealed is as follows: "The Primeval Cell, together with the Proof that Granite, Gneiss, Serpentine, Talc, certain Sandstones, also Basalt, and finally Meteoric Stones and Meteoric Iron, consist of Plants." This is only the carrying a little farther of the same style of observation as that to which we are indebted for the Eozoön, and that some one should follow this line of research to the highest pitch of absurdity seemed to be the one thing wanting to give the Eozoön the *coup de grace.*

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* Am. Jour. Sci., 1876 (3), XII. 395.

† Proc. Am. Assoc. Adv. Sci., 1876, XXV. 208.

‡ Geology of New Hampshire, III., Part IV. pp. 40, 41; Am. Jour. Sci., 1878 (3), XVI. 396.

§ "When I now look through my thin sections and find in them the plainest evidences of reproductive cells (Brutzellen) belonging to the plant, ... I am obliged to believe that all those who worked at the Eozoön, myself included, were smitten with blindness." (Hahn, Die Urzelle, etc., p. 19.)

As already mentioned, it is held by Dana, as well as by many other geologists, that the occurrence of limestone in the Azoic series is evidence of the existence of life at the time of its formation. The same view is also maintained with reference to the presence of graphite in these rocks. In upholding these views it is the authority of Bischof which is chiefly followed. This author, in his classic work on chemical geology, declares in the most positive manner that those geologists who believe that the earth has cooled from a condition of igneous fluidity cannot do otherwise than admit that all the carbon on and in the earth is of secondary origin, that is to say, was not present in the primeval earth (in der Schöpfungsperiode nicht vorhanden war). The statements which he brings forward to sustain this view are, however, not correct.

The first of these alleged facts is, that carbon could not have existed in contact with the oxides of iron and the other metals in a melted magma, because it would necessarily have been oxidized to carbonic acid and carbonic oxide.* In answer to this it may be stated, that, if graphite cannot exist, it certainly can be formed, under these conditions, since it is a well-known fact, daily witnessed by those engaged in blast-furnace operations, that this material separates out in distinct crystalline plates and scales from the melted iron as it cools; moreover, the presence of graphite in furnace slags is a matter of not infrequent occurrence. The presence of graphite in the metallic iron meteorites may also be mentioned in this connection, as strong evidence that carbon can exist in connection with melted iron, or be in some way separated from it. This graphite occurs in some cases in nodules completely enveloped in the metallic mass. In the iron-bearing basalts of Greenland, graphite is also found both in the metallic iron and in the basaltic rock, in which this metal is enclosed.†

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* Bischof, Jahrbuch der chemischen und physikalischen Geologie, 2d edition, I. 662, 663.

† See Törnebohm, in K. Svenska Vet. Akad. Handlingar, Band V. No. 10; also, Daubrée, Géologie Experimentale, p. 555. Lawrence Smith, Mémoire sur le Fer Natif du Groenland, in Ann. de Chim. et Phys., (5), XVI. 452–505.

Furthermore, Bischof states as additional evidence of the truth of his assertion that carbon cannot have existed in the primeval earth, that this element is not found in the unstratified crystalline rocks which, according to the views of the plutonists, were lifted up from beneath. ("Da die ganze Gruppe von nicht geschichteten krystallinischen Gesteinen, welche nach Ansicht der Plutonisten von unten heraufgehoben werden, in ihrer Masse keinen Kohlenstoff enthalten," etc.)

This, again, is an entire mistake on the part of Bischof. The largest and most important deposit of graphite in the world — that of the Alibert mine — is described by various geologists who have seen it as occurring in granite, or as lying between granite and syenite. In fact, the normal occurrence of graphite may be said to be in the older gneissic and schistose rocks, in which it either forms lenticular masses of greater or less size, or is disseminated through the rock in scales, or thin layers.

One of the most celebrated known localities of graphite is in Bavaria, in the so-called Passauer Wald, where it has been for a long series of years extensively worked. Gümbel has made a thorough investigation of this region. The rock in which the graphite is contained is gneiss, called by this geologist "Graphitgneiss," because the mineral in question is disseminated through the rock just as the mica is, forming apparently an integral part of it; not — as Gümbel thinks is evident — replacing the mica, but being an original constituent of the gneiss. To use his own words: "We must therefore consider the graphite to be as much a primary formation [primäre Bildung] as are the other minerals of the gneiss, of which it makes a constituent part."

Graphite occurs in the crystalline limestones associated with the older crystalline or azoic rocks; but not — so far as we know — aggregated into masses of sufficient size to be anywhere an object of profitable exploration. The normal mode of occurrence of graphite in limestone seems to be in the form of thin scales disseminated through the rock, and these scales are larger and more distinctly developed where the limestone is most crystalline.

Indeed, so far are the statements of Bischof from the truth, that it may be stated, as the result of geological observation up to the present time, that true graphite is "almost exclusively confined to granite, gneiss, quartz, mica-slate, crystallized limestone, and the older slates." *

That graphite has been formed from vegetable matter, at least in a manner similar to that in which coal has been, as is claimed by so

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* Jukes and Geikie, "The Student's Manual of Geology," 3d edition, 1872, p. 56.

many geologists, seems to us in the highest degree improbable, for the reason that true graphite has never been found — so far as our knowledge goes — in connection with coal, whether the latter be in its ordinary bituminous condition or in its nearest approach to pure carbon as anthracite, as it ought to be if it was formed in the same way in which coal has been, and was only the carrying forward of that process to the last stage of carbonization. If graphite was the final result of the working of the agencies by which vegetable matter has been turned into anthracite, it seems impossible that, somewhere in the vast area covered by the anthracitic formation in this and other countries, there should not be at least some distinct traces of graphitic material found.

It is stated in the various text-books of mineralogy and geology, that graphite has been formed by the passage of dikes of eruptive rock through coal beds. This, however, does not seem to be confirmed by the result of more recent and more careful observations than those made in the days to which many of the statements in our text-books belong. So far as our own observations go, the tendency of the eruptive rocks, in their passage through coal, is to change this into a material very different in character from graphite.

Much of what is called "plumbago" is by no means graphite. It is, rather, a mixture of particles of carbonaceous matter with rock; the result being, in certain cases at least, a refractory material which can be used for some of the purposes for which graphite is employed. We repeat, therefore, that we have never seen, and know of no authentic account of any one else having seen, pure graphite and coal so associated together as to make it necessary to believe that the former was produced by the decomposition of vegetable matter, as we have abundant reason to believe that coal in all its forms has been.

The graphite which is formed artificially at the present day is, so far as we know, exclusively the result of operations carried on at a high temperature.* The separating out of graphite in cast-iron and slags, and the formation of the material in gas retorts, are striking instances of this.

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* The same may be said of the more or less successful attempts to make artificial diamonds. The experiments of Mr. Hannay in this line, in which he claims to have succeeded in forming this gem, although by no means affording any encouragement for the belief that it can be manufactured with pecuniary profit, seem to have resulted in the production of something which had the physical characters of the diamond. High temperature and immense pressure were the most important factors; but it is stated by Mr. Hannay that the presence of nitrogen seemed to be a *sine qua non*. This last-mentioned item may be noticed in connection with what is said farther on in the text in reference to the part played by cyanogen in the formation of artificial graphite.

The most abundant source of artificial graphite, however, is in connection with the manufacture of soda by the Le Blanc process; for here the quantity produced is so large that it has been seriously proposed to use it for the manufacture of lead pencils. This graphite, according to R. Wagner, is formed at a certain stage of the process of converting the caustic soda into the carbonate; at which time the cyanogen present — which must have resulted from the preceding treatment of the saline mass at a high temperature in the reverberatory furnace — undergoes decomposition, the carbon separating out in the form of graphite. The same origin is claimed by Wagner for the graphite occurring in cast-iron. According to him, it is not the carbon, dissolved in the iron itself, which separates out when the latter cools and solidifies, but that which is derived from the decomposition of the cyanides present in large quantity in the iron as well as in the slag. These cyanides undergo decomposition, the carbon appearing as graphite, and the nitrogen going off in the form of ammonia, well known to be one of the products of blast-furnace operations.*

Thus it appears that we know of no other way in which graphite can be artificially formed than indirectly in connection with, or as one of the results of, some process or operation carried on at a very high temperature.

The position assumed by Bischof with reference to the diamond is also based on imperfect knowledge of the facts connected with the occurrence of this most remarkable substance. It was Bischof's idea that the diamond was formed in the superficial detrital material of recent age, in which this gem had until within a few years been exclusively found. He believed that it was simply a result of the decomposition of organic matter, under conditions which prevail everywhere; so that, if his view were the correct one, the diamond, instead of being the most precious of gems and being found in exceedingly minute quantity, should be literally "as common as dirt."

The facts in regard to the diamond, from the standpoint of our present knowledge, are simply these: Wherever detritus of crystalline rocks occurs unconsolidated, so that it can be cheaply "handled," — that is, moved and washed, — there gold either has been in former times or is now being obtained, although not by any means always in remunerative quantity. Most of these detrital deposits, where rich enough to pay for working, have already been washed over, and have become exhausted of their gold. Those which are still the object of exploitation on a large scale usually produce diamonds as well as gold; as, for instance, Australia and California, not to speak of the less important Appalachian gold-fields. It is true that the quantity of diamonds thus produced is very small, so that there would not be the slightest probability that the auriferous gravels could ordinarily be worked with profit for this gem; although we have reason to believe that by the common methods of gold-washing much the larger proportion of the diamonds would be lost or passed over unseen. Still, we are obliged to admit that the diamond must originally have had its birthplace in the same crystalline rocks from which the gold has been derived, and out of whose detritus both these precious substances are washed. There is no more reason to suppose that the diamonds were formed in the gravel posterior to its abrasion from the solid rock than that the gold was.

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* See Sitzungsberichte der phys.-med. Gesells. zu Würzburg, 1869, p. xxii.; also, Wagner's Jahresbericht, 1872, p 57.

The occurrence of the diamond in Brazil, in the detrital formations, in no respect differs from that indicated for California and Australia, except that these are localities where this gem is unusually abundant, and where the detrital material is more ferruginous than it ordinarily is. The diamonds have been deposited in a modern gravel, made up of the ruins of a much older crystalline formation; and this gravel has been, in places, reconsolidated into a rock by having become impregnated with a ferruginous solution. Whether the diamonds came originally out of the crystalline metamorphosed sedimentary rocks, or out of the eruptive masses with which these are associated — the eruptive material often predominating very largely over the sedimentary: this we know not, as the diamonds are always found loose, in crystals, and separate from any of their original matrix.

In fact, it is only within a few years that we knew anything definite about the occurrence of the diamond in its original matrix. The locality we refer to is, of course, South Africa, where this gem occurs, within certain well-defined limits, in much larger quantity than was ever before known. But here the matrix, or enclosing rock, is unquestionably eruptive. It not only has the mineralogical characters of an eruptive rock, but the whole style of its occurrence is such as to stamp it as unmistakably volcanic. Everything about the South African diamond-bearing localities is remarkable and exceptional; and thus far the theory of the origin of the diamond has been but little advanced by the observations made in that region. All that can safely be said is, that it seems as if the idea that a high temperature had been one of the factors in the mysterious operation of making the diamond had received a certain additional amount of corroborative evidence in consequence of the association of that gem with volcanic materials in the most productive diamantiferous district the world has ever known.

That the conditions under which this precious gem has been formed are very exceptional, can be safely inferred from the extremely small amount of the material which has been originated. Not that the diamond is limited, or almost exclusively so, to one locality, like certain minerals, — as, for instance, cryolite and red oxide of zinc. It occurs, on the contrary, all over the world, but never — so far as yet observed — in masses weighing more than a few hundred grains; while, if all the specimens of this gem which go to help make up the crown-jewels of all the empires and kingdoms of the world were put together, their united weight would certainly not exceed a few pounds.*

The inference from that which has been stated above is, that we are not justified in assuming that the occurrence of graphite in the azoic rocks is a proof that this material has resulted from the action of organic agencies, or, in other words, that life existed on the globe at the time these rocks were deposited. The fact that no recognizable traces of such life have ever been found in connection with the graphite of the Azoic series, is decidedly an important item in this connection; and we consider that geologists are not justified in assuming the presence of life when they not only have no positive evidence of its existence, but when the theoretical probabilities are strongly in opposition to this view.

The idea that the presence of carbonate of lime must necessarily be taken as a proof of the former existence of life — as is so positively asserted by Bischof, Dana, and many other geologists — seems to us entirely at variance with the facts. It is impossible for any one familiar with the mineralogical occurrence of carbonate of lime to deny that the formation of this material is a process which is going on, in innumerable localities and on a grand scale, without the intervention of organized existences.

Every metalliferous vein is likely to have, and in many instances such veins do have, the metallic sulphides which they contain — sulphur being by far the most common mineralizer of the metals — more or less completely converted into carbonates at their outcrops. Thus, while chalcopyrite is the most common ore of copper, the carbonate of the oxide of this metal is very frequently found, and sometimes in large quantity, in and near the outcrop of such veins. Water takes carbonic acid from the air, and, percolating downwards, converts a great variety of mineral substances more or less completely into carbonates. This is a process which may be said to be going on everywhere on a grand scale.

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* The total weight *in the rough* of thirteen of the largest and most celebrated diamonds in the world was only a little over a pound.

Calcareous spar (calcite) is one of the most common of veinstones, occurring in very large masses, both in regular veins and in those masses which belong to the segregated form of metalliferous and mineral deposits.

Again, carbonate of lime, or of lime and magnesia, is among the most commonly occurring products of the alteration of eruptive rocks.

Much of the crystalline limestone, or marble, which occurs in the Azoic series, seems to us to belong to the segregated form of occurrence. Some of it is certainly of this character, as has been already mentioned in connection with the question of the organic character of the Eozoön. If any of it is really bedded limestone — that is, rock which was formed contemporaneously with the formation of the beds with which it is associated — it seems to us clear that there are stronger reasons for believing that this has been the result of a chemical precipitation, than that the calcareous material has been formed through the agency of life.

In default of other evidence of the presence of the results of organized existence in the azoic rocks, it has been maintained by some that the occurrence of ores of iron in extraordinary quantity in that series furnished the desired proof. The facts are, however, that some at least of the iron thus occurring is of eruptive origin; that the oxide of iron is a mineral commonly and abundantly found making an essential component of volcanic rocks; that metallic iron is so found in large quantity, — in one region, at least; that there is strong reason for believing that metallic iron forms, if not the whole, at least a large part, of the earth's interior; and, finally, that a large portion of the material which comes to us from outside our planet is metallic iron. All this, we think, is amply sufficient for a refutation of the theory, that the presence of the ores of iron is a proof of the existence of life at the time when the rocks were formed in which those ores occur.

That it should be seriously maintained that the presence of sulphur is evidence of the presence of organic agencies, seems to us still more extraordinary than that the ores of iron should be so regarded. Sulphur is one of the most abundantly diffused of the elements. The sulphurets of the various metals occur all over the world in vast quantity, and as low down as mining has ever penetrated. The facility with which the metallic sulphurets are decomposed by water when at a high temperature, and again the liability to decomposition, in a variety of ways, of the sulphuretted hydrogen thus formed, are matters familiar to those who are moderately well acquainted with elementary chemistry. We need, in this connection, only state the simple fact, that, only a few years ago, nine tenths of all the sulphur consumed in the world was obtained from a region where all the facts show clearly that this sulphur was the result of volcanic agencies. This alone is sufficient evidence on the point in question.

It has also been claimed that the presence of apatite in the Azoic rocks was an indication of the existence of life at the time these rocks were deposited. Since phosphoric acid, probably largely in the form of phosphate of lime, has been found in almost every kind of eruptive rock, including granite, porphyry, and both ancient and modern lavas, it seems that the theory which makes this mineral necessarily the result of organic agencies, is not supported by facts. The earliest plants and animals which required phosphoric acid for their development cannot have taken it originally from the atmosphere, since it does not exist there. They must, therefore, have obtained it from the earth, unless we are willing to admit that it was created by th [illegible].

In view of all that has been set forth in the preceding pages, we consider that we are fully justified in saying that the results of geological investigation during the past thirty-five years have given no encouragement to the idea that below the well-known Primordial zone — the Potsdam sandstone of American geologists — there is another series of fossiliferous rocks. We think that the nomenclature of the formations should be made to correspond with the actual facts, rather than with views which have no other than a theoretical basis. It would no doubt be in harmony with the ideas and wishes of many palæontologists, that there should be found a series of rocks occupying the position of the Azoic system replete with organisms of a lower type than that of the "Primordial Fauna" of Barrande.* This desire has, no doubt, powerfully contributed to the general acceptance of the Eozoön as a relic of life, although — as it seems to us — the entire absence of foraminiferal life in the lowest Silurian, throughout the world, places the evolutionists who accept the Eozoön in a more difficult position than they would occupy if they rejected it altogether. It would be better for them to take the ground occupied by F. Roemer, and say that "the strata containing the Primordial Fauna are the oldest fossiliferous rocks, either because the rocks which are still older were originally unsuited to the preservation of traces of life, or had become so in consequence of subsequent changes, or else because the organisms which preceded the Primordial Fauna were of too perishable a character to be preserved." At all events, let them recognize, with Roemer, that, so far as our present knowledge goes, there are no fossils older than those of the Primordial Fauna.

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* "In his address to the British Association at Bath, he [Lyell] naturally revelled with delight at the discovery of the *Eozoon Canadense* in the Lower Laurentian." — Murch, in Geol. Mag., II. (1865), 98.

Of all the results of geological and palæontological investigations during the past half-century, there is no one so remarkable as the revelation of the existence of the so-called Primordial Fauna. It is now clearly established that there was a time when life was represented by a few forms, which were essentially the same all over the globe. What has long been known to be true for Europe and America has been recently supplemented, for Asia, by the investigations of Richthofen in China, where the peculiar primordial fauna seems to be largely developed, bearing, as Professor Dames remarks,* "an astonishing resemblance" to that of North America and Scandinavia. We have, namely, in China, the same intermixture of trilobites, either belonging to the genus *Concocephalites*, or closely related to it, together with the usual primordial brachiopods, *Orthis* and *Lingulella*, which everywhere characterize the oldest rocks in which any "decipherable traces" of life have been found. And, as if in utter contempt of all theories, we find the trilobites disappearing entirely in early geological times, while the brachiopods remain almost or entirely unchanged up to the present epoch.

We have thus, as we think, clearly established the truth of the statement, that the stratified rocks designated as Azoic by Foster and Whitney, and included within the Archæan of Dana are — so far as present evidence goes — non-fossiliferous. A persistent search for nearly half a century, in all parts of the world, for traces of life in infra-Silurian formations has not resulted in success. We consider, therefore, that geologists who prefer the guidance of fact to that of theory, and who respect the law of priority in nomenclature, will continue the use of the name Azoic for the rocks described under that name by Foster and Whitney. At the same time, it is desirable that a more definite understanding should be had as to the nature and age of the rocks to be designated by that term, with especial reference to the name "Archæan," introduced by Dana, as already mentioned, and which has of late years to a considerable extent replaced both the Azoic of the Lake Superior Survey and the Laurentian and Huronian of the Canada geologists.

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* China, Vol. IV. p. 7.

Dana, in that edition of his Manual in which he first introduces the term Archæan, expressly says that "this formation [the Archæan] was first distinctly recognized in its true importance in the Report of Foster and Whitney on the Lake Superior region, where it was named 'the *Azoic system*,'" so that the natural inference would be that he intended his "Archæan" to be the exact equivalent of the "Azoic" of the Lake Superior geologists. As defined by him, however, this new designation has by no means the same signification as has the term which it was apparently intended to replace.

In endeavoring to ascertain, by examination and comparison of the statements made in reference to the Archæan in the latest edition of Dana's Manual, what rocks this author really did mean to include in that formation, we find considerable difficulty, so vague and contradictory are the expressions of his views on this point.

We are distinctly told, however, that "Archæan Time" includes "*the era in which appeared the earliest and simplest forms of animals*"; it also embraces, as we are informed, "*an era in which the physical conditions were incompatible with the existence of life.*" Thus it appears evident that the author of the term Archæan clearly intended to include under that designation a series of stratified fossiliferous rocks, and also other rocks, which preceded these in age, and were formed before life existed on the globe.

But we are informed by the same author, that the first appearance of life, of whatever rank that life might be, was an event of the highest interest in the geological history of the earth. We would go even farther than that, and say that it was an event far transcending in importance any other one which has ever taken place on this planet. And, bearing this in mind, we would insist that so great a transformation in the earth's condition should be recognized in our geological nomenclature. At all events, it would, as it seems to us, be in the highest degree unphilosophical to call by the same name rocks which not only differed in their geological age, but also in regard to the all-important point of having been formed before and after the introduction of life upon the globe.

The facts are, however, that the fossiliferous portion of Dana's

Archæan is only *theoretically* fossiliferous. He admits that "no distinct remains of plants have been found in it." Yet, as his theoretical views demand that plants should have existed before animals, he has no hesitation in asserting that the presence of graphite is "strong evidence that plants of some kind were abundant." He even goes so far as to state what these plants "must have been," namely, marine *Algæ*, lichens, and fungi. At the same time, although admitting that the Eozoön is a somewhat doubtful organism, he thinks that "animals of the lowest division of animal life *were probably abundant*" (in the Archæan).

If it be true, as Dana believes, that there existed, at a time previous to the epoch of the Lower Silurian, an abundance of animal and vegetable life, then the strata deposited at the time this life existed should be enrolled among the fossiliferous groups, with a special name indicating the relations which this life held to that of succeeding groups. They certainly should not be called Azoic, nor should they, on the other hand, be designated as Archæan, that name being used at the same time to include rocks necessarily destitute of traces of life and belonging to another epoch.

The truth is, however, that — so far as the present state of our knowledge goes — the *abundance of life* with which the Azoic is endowed is only a *theoretical abundance.* One could not well make a new palæontological subdivision based on graphite and calcite; hence the theoretically zoic rocks have had, of necessity, to remain with the practically azoic. Whenever a new fauna shall have been clearly recognized as actually existing below the Primordial, then the fact will no doubt receive welcome recognition, and the "Age" or "Epoch" be designated in accordance with the nature of the fauna thus made known.

Dana, however, not only includes in his Archæan the Azoic Series of Foster and Whitney, by him considered, on theoretical grounds, as being a fossiliferous formation; but he embraces under that designation, not only the granites and old volcanic rocks associated with the Azoic, and which took their present position before the lowest Silurian strata were deposited, but all eruptive, and indeed all crystalline rocks, with the exception of such as are the result of the metamorphism of strata of Silurian or post-Silurian age.

This is not only the necessary and logical inference from Dana's definition of the term Archæan, but it results clearly from his special designation of the rocks which he embraces under that name. The crust of the earth, according to his view, is Archæan; or, as he says, this is the "only universal formation." He further remarks, that the Archæan rocks "extended over the whole globe, and were the floor of the ocean and the material of all emerged land when life first began to exist." Moreover, he expressly enumerates among the occurrences of Archæan rock those areas of the earth's crust "which, in the course of the upturnings of mountain-making, have been pushed upward among the displaced strata, and in this way have been brought out to the light."

Thus, according to Dana's definition of the term Archæan, it would be legitimate to include under that designation the granitic axis of the Sierra Nevada, although that mass of rock seems clearly to have assumed its present position at some time near the close of the Jurassic epoch. In fact we do not see how it would be possible not to admit that Ætna, for instance, belongs to the Archæan, as defined by Dana, since this volcano certainly consists of material which has been "pushed upward" during the process of "mountain-making," and which evidently formed a part of the exterior portion or crust of the earth.

The only way in which we could avoid designating all eruptive rocks, including those of which modern volcanoes are built up, as Archæan, would be by taking issue in regard to exactly what is meant by that frequently used term, the "crust of the earth." A discussion of this question would, however, lead to no very satisfactory result; for it is probable that hardly any two geologists would agree in their views, if required to set forth exactly what they considered to be meant by the phrase in question.

It is true that Dana does not follow out his own definition to its logical end; since he, for instance, speaks of the eruptive rocks of the Connecticut Valley, not as Archæan, but as Mesozoic. Others, however, seem to have taken his language as it would appear on the face of it to have been intended that it should be taken, and have called eruptive rocks of various ages Archæan, without any reference to the geological time of their appearance in their present position, but solely because they appear to have formed a part of the original "crust."

That this method of grouping and nomenclature is entirely unphilosophical, it seems hardly necessary for us to state. The first and most important question in geological research is always, To what period does the formation under investigation belong? If stratified, what geological age is indicated by the fossils it contains? If eruptive, at what time was it erupted? To class geological formations of different ages together is extremely undesirable, and can only be admitted when the treatment of the subject is a purely petrological one; as if, for instance, we should speak of "sandstones," including those of all geological ages, but in such connection as would make the fact that the rock was sandstone the only point of importance with reference to the question under investigation.

We would then call the eruptive rocks associated with the Azoic, and which took their position in that formation before the deposition of the Palæozoic formation upon them, Azoic eruptive, designating the special rock by its lithological name. To the eruptive rocks of later date, we would respectively give the designation corresponding to that of the age or period when those rocks assumed their present position.

The granitic axis of the Sierra Santa Monica, therefore, is not an Archæan rock, but is a Tertiary eruptive, granitic, intrusive or axial rock, because it took the position in which we now see it during the Tertiary epoch.*

We come now to the second branch of our inquiry; namely, to the consideration of the question whether the Azoic series can properly be separated into two or more divisions, as has been done by the Canada Survey and by those who have followed its lead.

If we adopted the views and nomenclature of Dana we should at once admit that a division of the Azoic (Archæan) into two distinct groups was not only desirable, but imperatively necessary, since we can conceive of nothing more unphilosophical than placing stratified fossiliferous rocks in the same category with non-stratified and necessarily non-fossiliferous ones. To designate by the same term the stratified deposits of Lake Superior, which have remained as they now are since a time prior to the deposition of the Lower Silurian, and the eruptive granitic axis of a range which was not in existence until after the close of the Miocene Tertiary, seems to us entirely unreasonable, even from our own point of view, namely, that the Lake Superior rocks are in fact Azoic: how much more so, then, from the standpoint of Dana, who considers these same rocks to be fossiliferous!

If the Azoic rocks are really azoic, as we believe, then it follows, as a matter of course, that the series thus designated can only be separated into sub-systems on purely lithological grounds: if they are fossiliferous, as held by the Canada Survey, then it is equally clear that any subdivisions proposed for them should have a palæontological basis.

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* Although some geologists and lithologists are unwilling to accept the fact of the occurrence of an axial mass of granitic rock uplifting rocks of Tertiary age, yet it is nevertheless true. Every feature which ought theoretically to characterize such an occurrence, if it had really taken place, is present in the section offered by the Santa Monica range. The sharp uplifting of the stratified beds in the immediate vicinity of the intrusive mass; the remarkable metamorphic action of the granitic central axis on the adjacent stratified deposits, and the return of them to their normal conditions at a distance from the cause of the uplift: all this is plainly to be seen, and there is but one explanation for the *ensemble* of the facts. — J. D. W.

It is true that the Canada Survey did, for a time, uphold the idea that the Laurentian and Huronian were to be separated from each other on fossiliferous grounds, namely, that the one contained the Eozoön and the other did not; but this rather unsatisfactory basis of classification was soon abandoned. Later, it has been maintained by Mr. Murray, of the Newfoundland Survey,* that certain peculiar forms, supposed to be of organic origin, were characteristic of the Huronian of that region. Of one of these supposed fossils (the *Aspidella*) the palæontologist of the survey could only say that "its general aspect is that of a small *Chiton* or *Patella*"; but he hastens to add, that "it is not probable, however, that it is allied to either of these genera."† To us, the general aspect of the fossil in question, as figured by Mr. Billings, is that of a concretion intersected by small irregular cracks, and much more resembling the so-called *Septaria* than anything organic.

Specimens of *Aspidella* sent us by Mr. Murray, however, do not resemble in any respect the fossil figured by Mr. Billings. There are several indistinct impressions on the fragment of rock, neither of them like that fossil, and none of them necessarily of organic origin, at least so far as we are able to discover. They look more like spray markings than anything else with which we are able to compare them.

Of equally dubious character is the other of these so-called fossils, by which it is believed by the Canada geologists that the Huronian can be separated from the Laurentian. We refer to the *Arenicolites spiralis*, mentioned by Mr. Billings in the "Palæozoic Fossils," ‡ of which no description is given by him, it being only said to "occur near St. John's, in the Huronian." It is added, however, that "a more detailed description will be given hereafter." The real nature of this supposed fossil has already been sufficiently indicated by Dr. Wadsworth.§ Whether the *Arenicola didyma*, and the *Arenicolites sparsus*, of Salter, are or are not of organic origin, it is unnecessary here to inquire. That palæontologist considers them "burrows of annelides." We see little resemblance between these forms as figured by him and the *Arenicolites* of the Canadian Survey.‖

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* See *ante*, p. 380.

† Geological Survey of Canada, Palæozoic Fossils, Vol. II. Part I. p. 77.

‡ *l. c.*, p. 77.

§ Science, I. 39.

‖ A large number of specimens of the *Arenicolites* were collected by Dr Wadsworth in the vicinity of St. John's.

In the latter we see no indication that anything possessed of life had to do with their formation. The *Arenicola* is mentioned by Zittel, together with many other equally problematic bodies, which that eminent palæontologist dismisses with the remark that "these names have no zoölogical significance." *

Since palæontology affords no assistance in dividing the Azoic (Archæan or original Laurentian) into two or more sub-systems, it remains to be seen what does justify such a division: and here a few remarks in regard to systems in geology will be desirable. No fact is better or more generally recognized than this: that geological time can only be kept by the aid of palæontology, the entire systematic classification of the formations, and their separation into "ages" and "epochs" being exclusively based on the order of succession of organic life. No one would think of defining the period of a geological event by saying that it took place in the "sandstone epoch," or in the "limestone epoch." But this is, in point of fact, essentially what has been sought to be done in dividing up the Laurentian first into two groups, the Laurentian and Huronian, and afterward into various other subdivisions, as shown in the preceding pages. Such subdivisions, when the work has been well done and the order of superposition of the rocks correctly determined, may be of value, but only of local value, and they must be recognized as having no claims to be considered generally applicable to all regions.

To what depths of confusion geologists have descended in their endeavors to make out a distinct order of succession in the various lithological developments of the Azoic, and in their determination to uphold the divisions introduced by the Canada Survey, must have been made thoroughly apparent by what has been given in the preceding pages. We have seen the rocks moved about, from year to year, like the pieces in a Chinese puzzle, in a vain attempt to create the desired figure. And when to a false theoretical basis has been added entire incompetence in matters of geological observation and lithological determination, the confusion which has resulted has — as has been shown — become something almost incredible.

We may now proceed to consider, a little more in detail, how such methods as have been shown in the preceding pages to be current in the study of the crystalline rocks have come into vogue in this country, and to some extent abroad. That this has taken place largely through the influence of the Canada Survey under its old organization, it is thought no one will deny; and for the purpose of throwing light on the origin of the methods in question we naturally seek to ascertain what were the principles by which that survey was governed. No one conversant with the history of that organization will doubt that its methods and purposes were arranged and formulated by the geologist who was its head during the first twenty-seven years of its prosecution: that none of his subordinates did originate them, may readily be inferred from the fact that the second in authority had been trained as a midshipman, having previous to his joining the survey had no other experience than that gained on the Ordnance Survey of Great Britain, while he remained essentially an explorer and a stratigraphical geologist in all his methods. That the one who for so many years served as the mouthpiece of the Canada Survey did not prescribe its methods, can be readily inferred from his own statement,* that, for "official reasons," he did not dissent from Logan's views, the correctness of which he for many years doubted; and from the fact that at the very time when he says he did not believe in these opinions he was warmly supporting them in print. This is further enforced by the fact, that, almost as soon as Logan resigned, Hunt began to endeavor to overturn the work of the survey and the teachings of his previous years. In fact, he has quite recently started on a third crusade, with principles designed to upset all he has written before.†

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* Zittel, Traité de Paléontologie, Tom. I., 1883, p. 576.

The only other officials who, before the closing years of Logan's work, bore any prominent part in the study of the older crystallines were a young civil engineer, and two persons whose knowledge of geology had been chiefly acquired by practical cultivation of the soil.

Logan alone then seems to have been the motive power of the survey; and it now is necessary to ascertain in what way and under what influences he was prepared for his geological work.

From Harrington's Life of Logan we learn that the latter was employed in the counting-house of his uncle, in mercantile pursuits, from 1817 until about 1831, when he went to Wales as the business manager of some copper-smelting works in which his uncle was interested. Later, he added to this the business of coal mining. Since he requests his brother to purchase and forward to him "some good work on mineralogy and geology, Dr. Dickson will be able to tell you which are best," we may infer that he not only knew nothing of the subjects of, or the workers in, geology or mineralogy, but also that he, at that time, had no books relating to these subjects, although he was then thirty-three years of age.*

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* See *ante*, p. 458.

† The Origin of Crystalline Rocks. Abstract of a paper read before the Royal Society of Canada, May 21, 1884.

In 1833 he appears to have begun his mineralogical and geological work in an amateurish way; and later to have undertaken to lay down the geology of the "South Welsh Coal Basin" on the maps of the Ordnance Survey. A description of the geological map thus made constituted his first scientific paper, which was read† in 1837, *at which time he was thirty-nine years of age.*

Logan gave up his business in Wales in 1840, proceeded to Canada; and, in 1841, visited the coal-fields of Nova Scotia and Pennsylvania. At the time of his appointment as Director of the Canadian Survey, in 1842, the only scientific papers he had read before any scientific body (only one of which had been published) were devoted to questions relating to the geology of coal; and in their recommendations of him for the directorship De la Beche, Murchison, Sedgwick, and Buckland placed all their emphasis on his skill as a geological surveyor of coal-fields.‡

It can thus be seen that Logan, who was forty-four years old, had reached an age when most men's ideas and methods are fixed, the remainder of their lives being spent in developing them. He was purely a stratigraphical geologist, having had experience only in the study of the well-marked stratified formations. Having then and ever after "only a limited knowledge of chemistry, mineralogy, and palæontology,"§ and, so far as we can learn, no acquaintance with crystalline and eruptive rocks, beyond that acquired in the examination of some dikes in the coal measures, Logan was set at work in a country in which he was brought face to face with some of the most difficult problems with which a geologist has ever had to cope — problems which demanded for their solution a training entirely different from that which he had. Now at the period when Logan began his study of geology, and during much of the time when he was the head of the Canadian Survey, the rival theories of Werner and Hutton were yet bones of contention, in a disguised form, while Lyell's publications were exerting a great influence. If we turn to Logan's early reports on the Canadian geology it will be seen that in the study of the older crystalline rocks he follows Lyell implicitly.

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* Harrington's Life of Logan, 1883, p. 50.

† Proc. Brit. Assoc., 1837, VII. (sec.), 83–85.

‡ Harrington's Life of Logan, pp. 126–132.

§ Ibid., p. 397.

The latter held that the foliation planes in all gneisses were the results of stratification and proof of deposition from water — the sediments subsequently having been altered by subterranean heat. Those rocks which had been classed as primary, Lyell called *hypogene*, dividing them into an *unstratified* or *plutonic series* and an *altered* or *metamorphic series*. He also contended that "all the hypogene strata, beautifully compact and crystalline as they are, have once been in the state of ordinary mud, clay, marl, sand, gravel, limestone, and other deposits now forming beneath the waters."*

Following the above views of Lyell we see Logan at the outset giving the name "Metamorphic Series" to the older crystalline rocks, assuming that the planes of foliation were stratification planes; and stating that the "syenitic gneiss" or granite possessed "an aspect inducing the theoretical belief that they may be ancient sedimentary formations in an altered condition." † Such a belief, if simply looked upon as a theory, to be proved or disproved by the light of future evidence to be carefully sought for, would not have done great harm; but such was not the method of the Canada Survey, whose officers never took one step toward ascertaining the correctness of their theoretical belief. Yet we find Logan declaring, in 1863, that the Geological Survey had shown, in 1846, that the Laurentian consisted of "a series of metamorphic sedimentary strata underlying the fossiliferous rocks of the province," Hunt, in 1855, making a similar statement.‡

One who carefully reads the reports of that survey can hardly fail to observe that the entire geology of the crystalline rocks was worked out on the supposition that they were stratified, and that the laws of their relations were those that Logan had employed in the study of coal-fields, a difference in the dip or strike of the foliation being considered sufficient for the establishment of a new geological formation. No examination seems to have ever been made for the purpose of ascertaining the origin and history of the rocks in question.

We will now proceed to examine, a little more in detail, the way in which the Azoic or Laurentian rocks came to be divided into two groups — the Laurentian and Huronian. This division originated in the confounding by Logan of the basaltic volcanic rocks interbedded with the Potsdam sandstone of Keweenaw Point with the basic or greenstone portion of the Azoic of Foster and Whitney as developed north of Lake Huron. The two series possess nothing in common beyond the fact that both are basic and both carry copper—one in the native state and the other in the form of the sulphide. Instead of admitting that the acidic and basic rocks of the Azoic formed one mixed series of eruptive and detrital rocks, Logan here left the gneissic and granitic rocks in the Laurentian and placed the basic ones in a new series—the Huronian—on account of the known unconformability of the Keweenaw Point rocks with the Azoic. Later Logan admitted *sub silentio* the mistake he had made in uniting the Keweenaw Point rocks with those north of Lake Huron, thereby abandoning the data on which the Azoic was separated into two series; yet he persisted in his two divisions, which from that time forward in reality rested exclusively on a lithological basis.

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* Lyell's Principles of Geology, 1833, 1st ed., III. 367, 374, 376; 1834, 3d ed., IV. 280, 281, 292; and all subsequent editions of the Principles and Elements, or Manual.

† *Ante*, pp. 331, 332.

‡ *Ante*, pp. 338, 342.

The publication, in 1863, of a volume ostensibly giving the evidence and data as obtained during the previous years of the survey, but which in reality presented as proved that which had only a theoretical basis, with the evidence largely omitted or disguised, contributed greatly to the overlooking of the previous reports, and the acceptance of this as a correct statement of results obtained, and of the nature of the evidence by which they were supported. This was further aided by the persistent misrepresentations of the facts made by Hunt, as pointed out in the preceding pages. These misrepresentations have been so persistent and glaring that we are compelled to say that we consider that Hunt's "Chemical and Geological Essays," his "Azoic Rocks," and his publications generally, cannot be taken as any authority as to what he or any one else has previously taught or held, until his quotations and statements shall have been carefully compared with the original publications In this matter we are fully in accord with that which Dana has again and again earnestly claimed.

If we examine the often repeated statement that the Huronian unconformably reposes on the worn edges of the Laurentian and contains the *débris* of the latter, it will be found that in every case in which the rocks referred to these two formations were found in contact in the Canadian district (seven in number), the Huronian, with but two exceptions, is said to be conformable with and to generally pass imperceptibly into the Laurentian. In one of these two exceptions the rocks show mutually intrusive relations, and in the other the Huronian abuts against and runs under the Laurentian.

In all cases in which pebbles and fragments of the Laurentian have been found in the Huronian, they were seen occurring high up in the latter series, and not forming basement conglomerates. All the other so-called proof of unconformity has been made out of the fact that the strike of the foliation in the two formations when not in contact has been found to be discordant — worthless evidence unless the rocks observed in both formations be proved to be sedimentary and the foliation be shown to be coincident with the stratification. Now if the Laurentian was an old metamorphosed sedimentary formation which had been upheaved and contorted, and on whose worn edges the Huronian had been laid down, the evidence of the fact ought to be overwhelming in amount after the country has been studied for so many years. Wherever the Primordial is found in contact with the Azoic, the basement conglomerates and the worn edges of the older Azoic are to be found, and a like condition should be observed if the Huronian is distinct from the Laurentian. But such is not the case, even Selwyn going so far as to declare that the supposed unconformity cannot "be said to be based on or in accord with the stratigraphical observations of either Logan, Murray, Bell, or myself."*

It is well known that any eruptive rock so soon as it comes in contact with erosive agencies will yield fragmental material even before it is cold, and that much eruptive matter is ejected in a fragmental state, so that in a mixed series of eruptive and detrital rocks nothing is more common than to have the *débris* of one enclosed in another, without that enclosure proving that the rocks differ in geological age. This is well known to be the case with the copper-bearing rocks of Keweenaw Point, and it has been shown that the iron ores of the Marquette district, which form a constituent part of the so-called Huronian, are overlain by a conglomerate containing the *débris* of the former — yet both are by every geologist placed in the same series.

The basis of fact which forms the main support of the twofold division of the Archæan — including under that designation all rocks lying below the lowest fossiliferous series — is this: the axial or eruptive portions of disturbed and mountain regions are largely granitic and gneissoid in character. These granitic, granitoid, and gneissic masses are brought to light in the cores of great mountain chains, where long-continued uplift of the original crust of the earth has, through a succession of geological ages, been furnishing the material from which the sedimentary formations were built up. That the gneissic or gneissoid rocks are closely allied to the distinctly granitic and not necessarily metamorphosed stratified deposits is clear to us, as the result of long-continued investigations in regions where rocks of this kind occur. Not that all gneisses are of this character; but those are ordinarily so which with granite make up the axial masses of disturbed regions. That the parallel structure of the materials forming gneiss is not necessarily the result of sedimentation seems to us clearly to result from that which has been done both in experimental and field geology within the last few years. It cannot be denied that a foliated arrangement or a parallel disposition of the mineral elements of various sedimentary rocks can be, and often has been, induced in them after their deposition, and that this parallel arrangement is not by any means necessarily coincident with the planes of stratification. This fact alone is absolutely conclusive in favor of the idea that parallel arrangement of the mineral constituents of a rock — in other words, a gneissic structure, in rocks of the granitic family — is not proof of sedimentation.

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* Notes on the "Life of Sir W. E. Logan," 1883, p. 3.

Overlying the granitic and gneissic axial rocks we are likely to find — and in many cases do find — the stratified masses which were formed from the pre-existing crust themselves usually highly metamorphosed, because formed at a period of great chemical and mechanical activity. With these stratified and highly altered masses are associated eruptive materials — both interbedded and injected in dike-form — these also often greatly metamorphosed, and to such an extent that their original character is only with difficulty, and with the aid of the microscope, to be recognized. This protrusion or forcing out of eruptive materials seems to have followed the preceding uplift of the original crust, if not as a necessity, at least as something extremely likely to occur, as is shown by the fact that in so many great mountain chains we find volcanic activity more and more predominating with the progress of geological time. Since these eruptive materials come from a gradually increasing depth below the surface of the original crust, they are more basic than this, and, since as a rule they contain more iron than that crust, are darker-colored than the masses by which they are directly underlain. Hence the detrital beds formed from the *débris* of these more basic materials are themselves of a dark color, and as a result of their metamorphism we have the various slates, argillaceous, talcose, and chloritic, which so commonly rest upon the granitic and gneissoid rocks which form the core or axis of the disturbed region. With these slaty rocks are also associated limestone masses, which — so far as our observations go — are not ordinarily interstratified with the slates, but are of the nature of segregated deposits, having been formed posterior to the formation of the sedimentary beds with which they are associated, while the metamorphic agencies were at work making over the beds into the crystalline form in which we mow see them. Similar results have here and there been produced, although not on so grand a scale, during the succeeding geological ages, as we see exemplified in the veins and segregated deposits of later times, which are so well known to those who have occupied themselves with the study of vein phenomena. That these segregated masses of calcareous materials, which occur as veins and which are often metalliferous, are the result of organic agencies, no one who has studied them with care has ever for a moment supposed; and, as has been already stated, we believe that all the evidence is strongly in favor of the idea that the calcareous masses of the Azoic are also deposits from aqueous solution without the intervention of living organisms.

Pursuing the investigation still further, it is seen that the efforts of Logan to apply the principles of his stratigraphical geology to the crystalline rocks led naturally to the adoption of supplementary principles in order to sustain the sedimentary character of the rocks and to aid in their identification. Since the two series could not be distinguished by palæontological evidence, it became necessary to uphold the idea that lithological characters could take the place of palæontological ones as a basis for the arrangement of rocks in chronological order, and their division into groups. But this required that a still more important step be taken, — namely, to insist that all crystalline rocks were of Azoic age and that all non-crystalline detrital ones were Palæozoic or later; and this principle is now openly or tacitly assumed in all work in which the Canadian methods are followed. To say that crystallines necessarily differ in geological age from the non-crystallines, is equivalent to claiming that the crystalline lava that has flowed from Vesuvius is not of the same geological age as that of the ashes and mud which preceded and followed its eruption; for such we have found in some districts to be the exact relations of the older crystallines to the non-crystallines. Furthermore, it is now known that fossils occur in Scandinavia, Belgium, California, and elsewhere in crystalline rocks, — as, for instance, *ammonites* in greenstones.

In the application of their principles the Canadian Survey found it convenient to still further differentiate the rocks that had been classed with the Laurentian and the Huronian, and especially with the latter, since these are in part eruptive, in part detrital, and in part probably segregated deposits, so that their entire conformability with one another could not be expected. The first to be thus separated were the coarsely crystalline basaltic rocks, or the gabbros, which, on the "theoretical belief" that they were stratified, and on account of their cutting across the strike of some of the limestone belts — as any eruptive mass naturally would — were placed in a system newer than the Laurentian proper. Subsequent investigations have shown that these gabbros are — in part, at least — interbanded with the Laurentian limestones, so that they must be of the same age as those limestones, or else later intrusions. That they are eruptive rocks is the testimony of the present director of the Canadian Survey, and is in accord with the investigations of the best petrographers the world over; while our own investigations in the Adirondacks have led us to similar conclusions. Moreover they have been found by us occurring in dikes in the granite of Eastern Massachusetts.

Further, the Hastings series, although at first looked upon as conformable with and said to pass gradually into the Laurentian, was, on account of its having limestones associated with it and in conformity with the earlier results of Vennor, placed as an overlying formation. Vennor's work, however, having been continued ten years longer, appeared to demonstrate that the Hastings series was continuous with a lower portion of Logan's Laurentian. But Hunt, accepting the earlier work and ignoring the later labors of Vennor, has made out of the Hastings schists and granites the Montalban, and out of the limestones and quartzites the Taconian.

Again the felsites (orthopyres, petrosilex, etc.), which are known to be the old representatives of the modern rhyolitic lavas, and like them to occur in dikes, or to take the form of lava-flows, ashes, etc., and which were first united with the Huronian, have now been erected into a separate series — the Arvonian.

Only lithological principles are now used in making these divisions, and every fact pertaining to the origin and relations of these rocks is ignored; and since, while it is assumed that all these rocks are sedimentary, they were found to occur in dikes and other eruptive forms, it became necessary to hold that all eruptive (including volcanic) rocks were the products of a metamorphic (aqueo-igneous) action. Hence it was claimed that all these rocks had been deeply buried and then denuded,* and most extravagant views became current regarding denudation.

It thus came about that the coarser-grained granitoid and gneissic rocks were set apart as Laurentian; the gabbros and some of the more coarsely crystalline diabases and diorites were erected into the Norian; the felsites and quartz porphyries were placed as the Arvonian; the finer-grained diorites, diabases, melaphyrs, and chlorite schists were formed into the Huronian; the more friable granitic and gneissic rocks with the mica schists were classed as Montalban; and the quartzites, limestones, and argillites were united into the Taconian. Of course in each case the metamorphic fragmental forms of each rock were placed with the rocks they resembled, while the other forms of crystalline rocks were distributed through the groups. We give below these arrangements in a tabular form; and in order to aid those geologists who believe in the lithological subdivision of the crystalline rocks into geological formations, we would propose another arrangement, which will be still more in harmony with their views. Thus we would place all the granites, gneisses, and syenites in the Laurentian; erect the magnetites, menaccanites, hematites, and their associated jaspilite into a new series; do the same for the peridotites, including the serpentines; but leave the Norian, Arvonian, and Huronian as they now stand. Further, we may place the porphyrites in a new group; limit the name Montalban to the mica schists, and the Taconian to the limestones; and place the quartzites, conglomerates, and argillites in three additional and distinct groups. All these divisions can be supported by quite as satisfactory evidence as that on which the formations now accepted are sustained. For instance, there is indubitable evidence that the Marquette iron ores are unconformable with the Huronian; the segregated limestones with their associated rocks; the eruptive peridotites, and the resulting serpentines, with theirs, etc.

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* Advocated by Lyell in 1833 and later.

Present Chronological Arrangement of the Crystalline Rocks.

Coarse-grained Trachytic Rhyolitic Rock.	LAURENTIAN.	Coarse-grained compact Granites and Gneisses.
Coarse-grained Basaltic Rock.	NORIAN.	Gabbro, and some Diabases and Diorites.
Compact Rhyolitic and Jaspilitic Rocks.	ARVONIAN.	Felsite, Petrosilex, Quartz Porphyry, Jaspilite.
Fine-grained Basaltic Rocks.	HURONIAN.	Diorite, Diabase, Melaphyr, Chlorite Schist.
Trachytic and Metamorphic Rocks.	MONTALBAN.	Friable Granites, Mica Schists.
Metamorphic Rocks.	TACONIAN.	Quartzites, Limestones and Argillites.

Proposed Chronological Arrangement of the Crystalline Rocks.

Laurentian	Granites, Gneisses, and Syenites.
Siderian	Magnetite, Hematite, Menaccanite.
Ophian	Peridotites, including Serpentines.
Norian	Gabbros, coarse Diabases and Diorites.
Arvonian	Felsite, Quartz Porphyry, Petrosilex, Jaspilite
Porphyrian	Porphyrites.
Huronian	Diorites, Diabases, Melaphyrs, Chlorite Schists.
Montalban	Mica Schists.
Crystallian	Quartzites, Quartz Schists.
Taconian	Limestones.
Glacian	Conglomerates.
Pelodian	Argillites.

It would seem that enough has been given to show that the basis of the subdivisions of the Azoic rocks in Canada was a purely theoretical one, and that Logan's methods and opinions were such, when he commenced the survey, that no different result could have been anticipated. It was just as if a geologist should apply the principles used in studying the undisturbed strata of the Mississippi Valley, or the Grand Cañon, to the elucidation of the structure of Mt. Ætna, and attempt to divide its flows and dikes into distinct geological formations. One may take the utmost care in all his measurements, may count every step from Gaspé to Georgia, and make most beautiful maps and sections; yet, if he is unable to determine the characters of the rocks he is mapping, his work is worse than worthless, for every obscure dike that is met with and every segregated mass of limestone causes a new fold and contortion to be inserted. From the fact that the surface distribution only was sought in the Grenville series — in which the limestones are probably of chemical origin — it would appear to us that no reliance is to be placed on Logan's much vaunted work and sections here, beyond the question of surface distribution; and such seems to be the case with all his and his assistants' work on the crystalline rocks.

The present director of the Canada Survey appears to be sincerely endeavoring to base his work on better methods than those current under Logan's administration. All who are interested in the solution of the difficult problems of Appalachian geology will sympathize with him in these efforts; for, as has been already suggested, that which is done in Canada will, *if well done*, be of great assistance to those working on the south side of the Dominion line.

APPENDIX.

Since the first part of this work was put in type, another report on the geology of Keweenaw Point has been published by Professor Irving, in the Third Annual Report of the Director of the United States Geological Survey. The state of our knowledge up to the time of the casting of that portion of the work has been presented on pages 76–157, 482–492. In Irving's report the before-mentioned observations (*ante*, pp. 115, 116, 482–484) of Wadsworth at the Douglass Houghton Falls are accepted and pronounced correct in every particular but one. Irving then acknowledges that the copper-bearing rocks are continuous with the eastern sandstone below the falls; but in order to escape the dilemma in which this places him, he says that below on the stream is a covered space between the true eastern sandstones and those which every previous observer had called such, and that here is the junction between the sandstone and Keweenawan series. This space he said Wadsworth had bridged over in his imagination. To this the latter replied, "that, by digging in the stream and on the banks of the ravine, he had actually traced (not imagined) the relations of these rocks, going from those dipping five degrees up to those dipping twenty-five degrees, and that they were seen to form a continuous super-imposed series, no such cliff as imagined [by Irving] existing between them." *

Irving further claimed that at the junction of the sandstone and traps on the Hungarian River (*ante*, pp. 113–115) the sandstone was a loose piece, or, if not, the basaltic rock surely was, and that the prevailing dip of the sandstone was to the southeast. To this "Wadsworth replied that the dips given in the report [Irving's] appeared to have been taken from the frost-dislocated rock on the sides of the stream, while his [Wadsworth's] were taken in the bed of the stream, when the water was exceptionally low. He further stated that the sandstone at the junction was continuous with that seen below; that it extended across the stream and into the banks on both sides; while the baking and induration of it showed that it must have been overflowed by some heated rock. Again: the basaltic rock extended across the stream into both banks, and was found to underlie the conglomerate, and that he dug the *débris* of the former out of the overlying base of the latter. All this, he said, showed conclusively that these rocks were *in situ,* and proved that here the eastern sandstone and Keweenawan series were one and the same; also that this series could not be maintained, as first established." *

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* Science, 1884, III. 553.

Irving further denies the general correctness of Wadsworth's previously published statement relating to the sandstone quarry near Torch Lake (*ante,* pp. 117, 118), and maintains that, while he (Irving) finds traces of the trappean material in the sandstone, he does not find any of the porphyry material belonging to the conglomerates of the "Keweenawan series." This claim proves too much, for if this sandstone had been deposited against the mixed lava flows and detrital rocks of the copper-bearing series as Irving holds, and made up of their ruins, there the sandstone should be full of their *débris,* and the old rhyolitic and trachytic material ought to be far longer retained than the more easily perishable basaltic material; since even in the sandstones intercalated with the traps the basaltic *débris* is comparatively rare. Now Irving's statements are directly opposed to his own views; and the same may be said of the testimony of all those who claim that the sandstone near the traps is composed of different materials from those of the detrital rocks of the so-called Keweenawan series.

Wadsworth has since re-examined the specimens in the collection made with express reference to retaining the evidence in behalf of his previous statements, (*ante,* pp. 117, 118,) and he reiterates those statements with the exception of this correction, that on page 117, third line from the bottom, the word *felsitic* is misprinted *feldspathic,* as the context shows. He finds in these specimens an abundance of the bipyramidal quartz peculiar to ancient and modern rhyolitic rocks, and also the variation between the bedding planes and jointing, both being evident in the hand specimens. The previous statement (*ante,* p. 488), that Irving had adopted Wadsworth's view that the pebbles of the Keweenaw conglomerates were largely old rhyolites and trachytes, Irving denies, since the director of the U. S. Geological Survey had misstated his (Irving's) views.* Irving, in his claim that in "the Keweenaw series occur, as I was the first to announce, so far as I am aware, original masses, not only of basic but also of acid eruptives, and of eruptives of intermediate acidity, the various kinds constituting a continuous series from the most basic to the most acid," * is incorrect, since all this was distinctly announced some thirty years before in the Report on the Copper Lands by Foster and Whitney (1850, pp. 58, 59, 70, 71, 78, 79) in the language of the science of that time.

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* Science, 1884, III. 553.

In the Third Annual Report before referred to, Irving further incorrectly states that Foster and Whitney regarded *all* the acidic or jaspery rocks as metamorphosed sandstones, and all the conglomerates and sandstones as friction detritus.†

In Irving's report there is further given a description of the microscopic characters of the acidic rocks of the "Keweenawan series," in such a manner as to lead any one not conversant with the history of the subject to suppose that Irving was the first to make such an examination, although he was perfectly well aware of Wadsworth's previous labors in that direction (*ante*, pp. 113–112).

Attention has been previously called to his proceeding in the same manner in reference to the Marquette rocks (*ante*, pp. 497, 498). This statement was, however, met by Irving in a sophistical and misleading manner, and by a denial the correctness of which we do not grant. Later, Irving appears to have tried to correct his former injustice to the best of his ability.‡

Nothing appears in the recently published first and third volumes of the final report of the Wisconsin Survey calling for any modification of the earlier part of this work, since one volume is devoted to a theoretical discussion of assumed data, and in the other all the Azoic areas contained only one of the divisions of such rocks made by the Wisconsin geologists, and they are assigned to such divisions on lithological evidence only.

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* Amer. Jour. Sci., 1883 (3), XXVI. 321, 322.

† Foster and Whitney, Copper Lands, 1850, pp. 58, 59, 70, 71, 78, 79, 103, 109.

‡ Amer. Jour. Sci., 1883 (3), XXVI. 321, 322; 1884, XXVII. 130–134.

AUGUST, 1884.

INDEX.

[Bull. Mus. Comp. Zoöl., Geol. Series I. No. 1.]

Actinolite, joining quartz grains, 54; needles of, in garnet, 47; secondary origin of, 39, 47.
Actinolite rock, contact with granite, 53.
Actinolite schist, relation to the iron ore, 35.
Agassiz, A., Eastern sandstone deposited later than the trap, 96; geological structure at Douglass Houghton Falls, 115; mistakes the views of Foster and Whitney, 96; relation of sandstone and trap near Torch Lake, 95, 96.
Agassiz, L., on the origin of copper deposits, 88, 89.
Alteration products in plagioclase, 56.
Amygdaloid at base of traps, 81; defined, 128; deposited by water, 94; presence on Keweenaw Point denied by Bayfield, 77.
Amygdaloidal structure, origin of, 78, 81, 84, 86, 87, 88, 100, 101, 123, 129.
Amygdules, composition of, 130.
Analcime, igneous origin of, 80.
Andesite, probable occurrence of, 37, 38.
Apatite, in an old trachyte, 120; in gneiss, 57; microlites of, 37.
Argillaceous detritus, alteration and crystallization of, 58.
Argillite, 28; south of Marquette, 37.
Asbestus, chrysotile mistaken for, 66.
Ash-bed, confounded with detrital deposits, 112, 113; copper deposits in, 125; how formed, 91, 112; poor in copper near veins, 125; structure of, 125; tongues of, in trap, 113; tongues of trap in, 125.
Atlantic Mine, character of copper deposit at, 129; supposed "ash-bed" of, 125; thermal water action at, 125, 126.
Augite, alteration to hornblende, 37, 46; altered to hornblende and chlorite, 39; altered to hornblende and viridite, 42; altered to viridite, 37; cut by feldspar crystals, 37, 42; forming cores in hornblende, 37.
Australia, origin of placer gold of, 17.
Azoic age of iron region, 26.
Azoic system, defined, 7, 8, 9; first proposed by Foster and Whitney, 7; its relation to the Silurian system, 9; lithological characters of the, 8, 9.

Bacon, D. H., 131.
Banding, no proof of stratification, 28.
Bannan, Benjamin, volcanic origin of iron ore, 16.
Barite at McComber Mine, 51.
Basalt, alteration of, 70.
Basaltic rocks, alteration of, 105.
Base, alteration of, 37, 40, 44; alteration products taken for, 44; forming stone cavities, 42; globulitic form of, 40; unaltered globulitic, 44.
Bauermann, H., derivation of copper from the sandstone, 127; origin and sequence of minerals 95; on the deposition of the copper, 94, 95.
Bayfield, H. W., granite and trap of Keweenaw Point older than sandstone, 77; "Old Red" age of sandstone, 77.
Beaches, sea, in iron district, 31.
Bell, Robert, copper-bearing rocks of Permian or Triassic age, 97.
Bête Grise Bay, dip of sandstone at, 88.
Bibliography of the Geology of Lake Superior, 133–157.
Bigsby, J. J., Cambrian age of sandstone, 90; sandstone of "Old Red" age, 77.
Biotite, alteration product of hornblende, 56; connecting quartz grains, 54; cut by muscovite, 56; in granite, derived from schist, 54; secondary origin of, 36, 42, 46, 47.
Bohemian Mountains, origin of, 86.
Bolton, G. D., 132.
Braintree, Massachusetts, slates of, 72.
Breccia, overlying iron ore, 30.
Brooks, T. B., assumption that foliation and stratification are coincident, 25; bedded character of the iron ore, 18, 19; conclusions based on lithological characters, 24; copper-bearing rocks conformable with Huronian, 99, 100; evades the conclusions logically resulting from his own work, 24; formation xx. of, 71, 72;

granite dikes never seen in the Marquette Series, 74; his methods of work, 71; Lake Superior sandstone, always horizontal, 100; no basis for formations of, 75; on Huronian age of granite, 24; on indications of stratification, 18; on Laurentian age of actinolite rock, 53; on magnesian schists, 20; on origin of "soft hematites," 20; on the original state of the iron ore, 32; on the peridotite of Presque Isle, 75; on the quartzites, 30, 31; origin of diorite, 20; plasticity of iron ore, 21; "quartzite" of Republic Mountain, 34; report on the iron district, 18–22; sedimentary origin of iron ore, 20, 21; unconformability of the Laurentian and Huronian formations, 22.

Brooks (T. B.) and Pumpelly (R), Eastern sandstone younger than the copper-bearing rocks, 98, 99; the copper-bearing rocks conformable with the Huronian, 98, 99.

Burt, W. A., reports on iron district, 3–5.

CALCIFEROUS FORMATION, presence of, 103.

Calcite, in spike-like forms, 126.

Calcite veins, igneous origin of, 82, 83, 90.

California, origin of placer gold of, 16, 17.

Calumet and Hecla Mine, character of copper deposit mined, 129; contact of sandstone and trap at, 110; copper deposits of, 127; microscopic study of pebbles from, 118–120; sheet copper at, 126.

Cambrian Age, Huronian the equivalent of, 13; of Keweenaw Point sandstone, 90.

Canada, relations of Laurentian and Huronian in, 72.

Canada, West, copper mines said to be the most important in America, 106.

Carp River, age of rocks of, 4; quartzite of, 9; sandstone and quartzite of, 22, 23, 60.

Cascade Range, iron ore and quartzite of, 33; ore and jasper of, 32, 33.

Central Mine, a fissure vein, 129; best veinstone at, 130; copper deposits of, 127.

Chamberlin, T. C., report of the Wisconsin Geological Survey, 66.

Champion Mine, intrusive granite at, 57; ore of, 36; rocks of, 45.

Chazy age of Keweenaw Point sandstone, 95.

Chemist, duty of, 69.

Chlorite, alteration product after augite, 39; alteration product after hornblende, 56; in quartzite, 59.

Chlorite Schist, formed from a dike, 48; occurrence of, 20, 21.

Chocolate River, age of rocks of, 4.

Chromic oxide, not in Presque Isle peridotite, 61.

Chrysotile, mistaken for asbestus, 66.

Clay, masses in sandstone, 118.

Cleavage, no proof of stratification, 28.

Cleaveland Mine, lamination of schist, 41; relation of ore and schist at, 31.

Cliff, Captain, 131.

Cliff Mine, copper deposits of, 127; diabase of, 111.

Conglomerate, formation of, 84, 87, 128; local nature of, 122, 128; marks old sea-beach in Huronian, 31; of Keweenaw Point, lateral moraine formations, 85; of Presque Isle containing dolomite pebbles, 23; origin of, 122; overlying iron ore, 30; overlying peridotite of Presque Isle, 63; pebbles of melaphyr at base, 115; thermal water action on, 116; thickness of, 100; copper deposited in, 83, 127.

Conglomerate mines, mode of formation, 126, 127.

Connecticut, sandstone of, 79; trap of, 81.

Contact of diorite and schist shown in thin section, 37.

Continents, relative ages of American and European, 9.

Cooper and Patch, Messrs., 132.

Copper, concentration of, 92, 102, 109; conditions of deposition, 130; deposition of, 88, 90, 92, 97, 109; deposits mined for, 128, 129; derived from ores in older rocks, 109; derived from the sandstone, 81; description of spikes, 126; filling joints, 126; finely disseminated in lava, 126; in conglomerate mines, 126; of volcanic origin, 76; originally disseminated in the traps, 92, 102, 109; originally from primitive rocks, 81; original material brought up by the trap, 81; mode of occurrence of, 86, 124; profitable deposits of, 76, 77; reduction of, 90, 92, 93; replacing melaphyr pebbles, 126; torn from Azoic rocks by the trap, 94; united to silver, 79, 81, 105, 106, 109; use of, by Indians, 92.

Copper-bearing rocks, conformable with the Huronian, 99; easterly dip of, 26; Huronian age of, 108; Keweenawan age of, 108; lava flows, 86–88, 100–103, 105; lying between the Huronian and Potsdam, 99, 105, 107; of calciferous and Potsdam age, 94; Permian age of, 97; Quebec age of, 94, 97; Taconian age of, 105; Triassic age of, 97, 108; unconformable to the Huronian, 105.

Copper deposits, associated with heavy beds of trap, 126; not contact forms, 127; origin of, 89, 91–95, 106, 107, 130, 131.

Copper district, history of geological views in regard to, 76–107.

Copper Falls Mine, ash-bed of, 125; best veinstone at, 130; character of copper deposits mined, 129; copper spikes at, 126; Owl Creek, vein of, 129; relation of traps and sandstone at, 110–113; proofs of water action at, 125, 126.

Copper Harbor, rocks of, 80.

Copper pyrites, reported abundant in the iron district, 4.

Copper veins, origin of, 79, 80, 82, 84, 85, 88, 89, 90, 91, 92, 103, 106, 107, 108, 109.

Cordilleras, rhyolites of, 118, 119; volcanic rocks of, 48.

Credner, H., dikes near Marquette, 36; on the geology of the iron district, 17; on the original condition of the iron ore, 32.

Crosby, W. O., iron ores and jasper a "red clay" deep-sea deposit, 25.

Cumming, J. G., glacial action in early geological ages, 85.

Daddow, S. H., volcanic origin of iron ore, 16, 17.

Dana, J. D., copper in contact deposits, 127; on the formation of veins and the alteration of rocks, 106, 107; on the origin of copper deposits, 89, 93, 94; on the origin of the iron ore, 13; Potsdam and Calciferous age of the sandstone, 93; his theory of the copper deposits not based on facts, 131; Triassic age of the sandstone, 93; on the union of copper and silver, 105, 106.

Davies, D. C., errors in his work on "Metalliferous Minerals and Mining," 25, 26.

Dawson, J. W., his theory of the deposition of the copper, 92, 93.

Dead River, granite of, 56.

Deer Lake, diorite of, 42, 43.

Detrital deposits of iron ore and jasper, 30, 31.

Devitrification, in rhyolites and felsites, 33.

Diabase, alteration form of, 46; an altered basalt, 111; decomposition of, 43; eruptive in Eastern Massachusetts, 72; microscopic study of that of various localities, 39, 40, 42, 45; not mined on Keweenaw Point, 111; an old crystalline basalt, 39.

Diallage, in peridotite, 60, 61.

Dike, at Old Washington Mine, variations in structure of, 48; step form of, at Salisbury Mine, 42.

Dikes, near Marquette, microscopic study of, 36, 37; of iron ore and jasper, 30, 31, 32; of magnetite, 36; of schist, 48.

Diller, J. S., on the eruptive origin of felsite, 72.

Diorite, alteration products in, 36, 37; containing fragments of rocks, 39; erupted later than the jasper and ore, 51, 52; eruptive origin of, 17, 26, 46; eruptive through schist, 41; foliation of eruptive, 47; garnet-bearing, of Republic Mountain, 47; hill of, between Salisbury and Lake Angeline Mine, 49, 50; interstratified eruptive, 23; interstratified with schists, 14, 15, 17, 19, 20, 26; intrusive at Lighthouse Point and Picnic Island, 23; and at Republic Mountain, 47; microscopic examination of, from various localities, 39, 41, 42, 44, 45, 46, 47; mineralogically like the schist, 37; of Marquette district and the traps of Keweenaw Point the same, 12; passage into schist, 40; relation to jasper and iron ore, 51, 52; resembling chlorite schist, 42; resembling hornblende schist, 45; sedimentary origin of, advocated by various writers, 14, 17, 18, 19, 20, 25, 26, 40; younger than the Huronian, 17; secondary origin of minerals in, 46.

Dolomite, of Presque Isle, 2, 3, 10, 23; secondary origin of, in peridotite, 61, 62, 64, 65; stratified, of Rominger, 61; veins of, 64.

Douglass Houghton Fall, geological structure at, 95, 96, 115, 116.

Drift agencies, in earlier geological times, 85.

Eagle River Mine, H. D. Rogers on, 82, 83.

Eclogite, microscopic study of, from Old Washington Mine, 48.

Edwards Mine, eruptive character of iron ore, 35.

Emerson Adit, at Copper Falls Mine, 110, 111.

Enstatite, alteration of, 61; in peridotite, 60, 61.

Eozoön Canadense, alteration structure resembling, 114.

Epidote, in Republic Mountain granite, 54; secondary origin of, 37, 42, 56, 120.

Epidote veins, relation of, 84.

Fault, on eastern side of Presque Isle, 64.

Feldspar, alteration of, 39, 42; decomposition of, 38, 114, 117, 119, 120; decomposition products in, 55, 56; inclusions in, 36; inclusions of base in, 37, 44; replaced by kaolin, 43; secondary origin of, 113, 114, 119; stone inclusions in, 42; unstriated form sometimes due to alteration, 55.

Felsite, alteration of, 38; dikes of, 38, 39; eruptive characters of, 38; fluidal structure in, 38; intrusive, of Eastern Massachusetts, 72; jointing of, 37; microscopic study of, 38, 39, 118–120; its occurrence near Marquette not noticed by Julien, Credner, Brooks, or Rominger, 38; originally identical with modern rhyolites, 38, 39; its occurrence in the iron region, 75; its present difference from rhyolite due to alteration and depth, 38, 39; its relation to rhyolite, 118, 119.

Ferrite in pebbles, 113.

Field evidence, value of, 43, 74.

Fluid cavities in quartz, 38, 39, 44, 45; lying in fissures, 54.

Fluidal structure, 28; in felsite, or rhyolite, 38, 118, 119; segregation of minerals along lines of, 38; in granite parallel to contact planes, 57.

Foliation not necessarily coincident with stratification, 25; no proof of stratification, 72; of granite a fluidal structure, 57; relation to pressure, 53.

Forest Copper Mine, sandstone at, 100.

Fossils, absence of, explained by thermal water action, 116.

Foster, J. W., description of the iron region, 15, 16; on age of sandstone, 84; advocates the sedimentary origin of the iron ores, 6; on the origin of the "soft hematite," 16.

Foster, J. W., and Whitney, J. D., azoic age of district, 26; on the Carp River sandstone, 60; definition of the Azoic System, 7, 8, 9; on the formation of amygdaloid and conglomerate, 86, 87, 88; the results of their geological work sustained, 131; the iron age in geology, 9; on the metamorphic rocks, 8, 9; on the mode of occurrence of copper, 86; objections to their view of the relations of the copper-bearing rocks and Eastern sandstone in the vicinity of Torch Lake, 122; objection to their view of the structure of Presque Isle, 62, 63, 76; on the occurrence of the iron ore, 7; on the geological age of Eastern sandstone, 122; on the geological structure of Keweenaw Point, 86–89, 96, 97; on sand concretions in shale, 121; on the origin of the copper veins, 88; on the Potsdam age of the sandstone, 87; on the Presque Isle serpentine, 62; on the relations of the trap and sandstone, 111; their Report on the Geology of the Lake Superior Land District, 9; Silurian age of the sandstone, 86; their theory of the origin of the iron ore sustained, 68; the traps a succession of lava flows, 86.

Garnet, altered forms of, 53; columnar structure of, in schist, 48; dodecahedral crystals in diorite, 47; films of hematite surrounding, 48; inclusions in, 47; in diorite, 46; secondary origin of, 47.

Garnetiferous rock, microscopic study of, 48.

Geikie, A., microscopic distinction between lava flows and intrusive masses, 111; exceptions thereto in the Lake Superior district, 111.

Geological theories of copper district, 76–109; of iron district, 1–27.

Geology of Lake Superior, bibliography of, 133–157.

Glass, an unstable rock form, 125.

Gneiss, cut by diorite and diabase, 58; microscopic study of, from various mines, 57, 58; modified in contact with granite, 55; origin of, 57; sedimentary origin of, 26, 58.

Granite, contact with a garnetiferous actinolite rock, 52, 53; cutting diabase, 39; cutting quartzite, 55; cutting schist, 52, 57; eruptive in Huronian, 55; eruptive, of Eastern Massachusetts, 71, 72; eruptive origin of, 11, 24; foliation of, 52, 53; Huronian age of, 24, 25; igneous origin of, 10; intrusive in schists, 55; Laurentian age of, 14, 15, 19, 24, 25, 52; microscopic study of, from various localities, 53–57; passage of foliated into non-foliated forms, 57; passage into greenstone, 2; passage into serpentine, 2; of Picnic Point, 39; Potsdam age of, 91; presence of, in iron region, 75; red, intrusive in gray gneiss, 55; of Republic Mountain, 52–55; section of intrusive, in gneiss, 57; sedimentary origin of, 14, 25; younger than Huronian rocks, 53.

Granite Point, relations of granite and sandstone, 1, 2.

Granite porphyry, microscopic study of, 114, 117.

Graphic granite, alteration structure resembling, 114, 115, 117, 119, 120.

Gray, A. B., report on iron district, 4.

Greenstone, a metamorphosed sedimentary rock, 80; defined, 128; of Keweenaw Point, 111.

Greisen, eruptive origin of, 54, 55; a modification of granite, 55; of Republic Mountain, 44, 53–55.

Groundmass, alteration of, 43.

Hall, James, maintains the Potsdam age of the sandstone, 93.

Hancock Mine, "ash bed" not found at, 112, 113.

Hancock, Michigan, conglomerates at, 121.

Hematite, a decomposition product, 59; alteration product of magnetite, 39; crystal.

lizing out of molten magmas, 69; eruptive with silica, 68; films of surrounding magnetite and garnet, 48; forming a dike, 30; secondary origin of, 36, 48.

Hematite, "soft," at Jackson Mine, 32; composition of, 51; conditions of formation, 50; not bog-iron ore, 51; origin of, 16, 20, 25, 70; origin and characters of, 49–52; probable deposit near Lake Angeline Mine, 50.

Hodge, James T., origin of copper and silver veins, 84.

Home Mine, sandstone and ore at, 32; jasper dikes at, 32.

Hornblende, alteration of, 114, 117, 120; alteration product after augite, 37, 39, 42, 46; altered to chlorite and biotite, 56; foreign in andesite, 119; secondary origin of, 36, 37; pseudomorphs after fragments of, 38.

Houghton, D., his views in regard to the geology of the copper region, 77–81; geology of iron district, 2, 3; geology of Presque Isle, 2, 3, 62; variability of his views, 108.

Houghton, Michigan, conglomerate west of, 121.

Hubbard, B., on the geological structure of Keweenaw Point, 82; on the geology of the iron district, 3, 4; on metamorphism, 5; on the Porcupine Mountains, 83, 84; traps eruptive in sandstone, 82.

Humboldt, Michigan, granite intrusive in schist, 57; the rocks and ore of, 35, 36.

Hungarian Falls, sandstone at, 113.

Hunt, T. S., his erroneous observations in Eastern Massachusetts, 72; his views in regard to the copper region of Lake Superior, 93, 94, 99, 105; hematite a proof of presence of organic matter, 14; his views in regard to the iron region, 13, 19, 24; indefiniteness of his statements, 109; objects to decomposition theory of origin of "soft hematites," 51; not personally acquainted with the iron district, 40; on the Presque Isle serpentine, 62; on the sedimentary origin of greenstones, 25.

Huronian and Laurentian in iron region, 26.

Huronian, conformable with Laurentian, 25; contact with Laurentian not observed, 24, 25; according to Hunt, equivalent of the Cambrian, 13; eruptive granite in, 55; including rocks of two distinct ages, 31; relation to Laurentian, 70, 71; younger than the Laurentian, 22, 24.

Huronian age, according to Bigsby, distinct from the Cambrian, 14; of iron district, 13, 14, 15, 17; of Presque Isle serpentine, 62, 64.

Huronian rocks in iron region, 24; unconformable with the Laurentian, 22.

Indians, the customs of, 92; use of copper by, 92.

Iron age of geology, 9.

Iron district, country rocks of, 28, 29; eruptive rocks of, 46; geological structure of, 75; historical discussion of, 1–26; Huronian age of, 13, 14, 15, 17; jasper and iron ore of, 28–36; not visited by C. T. Jackson, 6; object of the investigation of, 27; sea-beaches in, 31; summary of geological views on, 26, 27.

Iron ore, breaking through schist, 31; chemical and metallurgical objections to eruptive origin of, 68, 69; has the color and streak of hematite, but is magnetic, 33; cutting schist, 31; a deep-sea deposit, 25; its deposition considered due to the presence of organic matter, 14; dikes of, 30, 32; difficulty in mining, 31; history of its discovery, 3, 4, 18; eruptive characters of, 32; eruptive origin of, 27, 67; form of eruption, 68; form of masses of, 29; Huronian age of, 14, 15, 17; interlaminations of, with jasper, 29; igneous origin of, 7, 9, 10; not interstratified with schists, 67; intrusive character of, 35; at Ishpeming, 30, 31; junction of, with chlorite schist, 30; the Laurentian age of, 13; limits between it and the jasper, 33; magnetic in contact with dikes, 43; magnetic state induced by secondary causes, 34; manner of intrusion, 35; in Marquette district, 6, 7, 14, 15; in Menomonee region, 3, 6, 7; in metamorphic rocks, 7; originally magnetite, 17; microscopic study of, intrusive in quartzite, 33; at Negaunee, 31, 32; in octahedrons, 33; origin of, 12, 13; its origin a matter of economic importance, 29; the original state of, 32, 34; plasticity of, 21, 67; according to Rivot, of Potsdam age, 91; proof of its intrusive character, 67; its relations to the country rock, 30–36; relation to schist, 31; secondary deposition of, 33; sedimentary origin of, maintained by various geologists, 6, 13, 14, 15, 17, 18, 20, 21, 22, 24, 25, 27; not in veins, 19, 29; wedge-shaped masses of, 31, 33.

Iron, oxides of, their action in reduction of the copper, 90, 92, 93, 97; precipitation of copper by, 130.

Iron, the protoxide of, an agent in the deposition of copper in veins, 90.

Iron, titaniferous, decomposition of, 48.

Irving, R. D., on the copper-bearing rocks, 104; on Keweenawan granite, 71; relations of trap and sandstone, 104; unity of foliation and stratification, 25.

Ishpeming, Michigan, contact of diorite and schist, 41; gneiss south of, 55; iron ore of, 30, 31; quartzite of, 59; red granite south of, 56; serpentine of, 65, 66; "soft hematite" mines of, 49, 50.

Isle Royale, geological structure of, 86, 87.

Isle Royale Lode, thermal water action on, 124.

JACKSON, C. T., the copper mines of Lake Superior probably not of permanent value, 81; copper and silver, of igneous origin, 81, 85, 86; copper veins valuable only in the amygdaloid, 86; on the deposition of the copper, 90; on drift agencies in early geological times, 85; on the formation of the zeolites, 91; on the geology of Keweenaw Point, 80–82; the igneous origin of calcite veins, 90; "New Red" age of sandstone of Lake Superior, 80, 85; the New Red sandstone of Upper Silurian age, 89; origin of amygdaloid sandstone and conglomerate, 84, 85; on the origin of the "ash-bed," 91; various opinions in regard to the age of the sandstone, 84, 89, 93.

Jackson Mine, diabase of, 43; intrusion of iron ore in schist, 31; jasper of, 33; "soft hematite" at, 32, 51.

Jasper, associations of, 29; brecciated structure of, 32; not coincident with lamination of schist, 31; cutting schist, 33; a deep-sea deposit, 25; dikes of, 30, 32; eruptive nature of, 35, 67; fluidal structure in, 33; fragments in quartzite, 59; interlaminations with iron ore, 29; limits between it and the ore, 33; microscopic study of, 33, 34, 44; at Negaunee, 31, 32; relation to diorite, 51, 52; uplift of, 51, 52.

Jaspilite, proposal and definition of the term, 75, 76.

Joint planes, no proof of stratification, 28; taken for bedding planes, 117.

Julien, A. A., dikes near Marquette, 36; doubts the presence of diabase in iron region, 45.

Junction line between diorite and schist, 40, 41.

KAOLIN, pseudomorpns after feldspar, 43; at Salisbury and McComber Mines, 50, 51.

Keweenaw Bay, dip of sandstone, 88.

Keweenaw Point, copper deposits mined on, 128, 129; geological structure of, 76, 77, 78, 79, 80, 81, 82, 85, 86, 87, 96, 97, 116, 127.

Keweenawan Series, numerous geological ages in, 118.

Keweenawan System, no basis for, 72, 131.

Keweenian Group, name first used by Hunt. 99.

Keystone Mine, magnetite dike at, 36.

Kimball, J. P., on origin of iron ore, 16; on the structure of the iron district, 15, 16.

Koch, Fr. C. L., on metamorphic rocks, 11; description of iron region, 11.

LAKE ANGELINE MINE, diorite of, 42.

Lake Gogebic, copper-bearing rocks near, 98.

Lake Huron, azoic rocks of, confounded by Logan with Keweenaw Point traps, 90.

Lake Superior Mine, greenish quartz rock of, 49; iron ore and jasper at, 30; microscopic study of the jasper of, 33; oven-shaped structure in, 51.

Lake Superior Region, methods of observation in, 27, 28, 73; rocks of mixed eruptive and sedimentary origin, 27.

Lamination, of jasper, 30; not proof of sedimentation, 28; of Picnic Point eruptive granite, 55; of the schists, 67, 68; of schist between dikes, 41; of schist cut by iron ore, 31.

Laumontite, red feldspar mistaken for, 121.

Laurentian, conformable with Huronian, 25; contact with Huronian not seen, 24, 25; doubtful basis of, 72; a name first applied to post-Tertiary deposits by Desor, 7; younger than the Huronian, 22, 24.

Laurentian age, of the granite, 14, 15, 17; of the iron ore, 13.

Laurentian granite, eruptive in Huronian, 70.

Laurentian rocks, in iron district, 24; unconformable with Huronian, 22, 24; younger than the Huronian, 22.

Lava, scoriaceous form of, preserved, 113.

Lava flow at Presque Isle, 9, 10.

Lava flows, mining of old, 124.

Lavas, geological age of, determined lithologically, 72.

Lesley, J. P., errors made in quoting the "Metallic Wealth of United States," 12, 13; opposes the igneous origin of any iron ore, 12.

"Leucoxene," alteration product after iron ores, 37.

Lherzolite of Presque Isle, 60–65.

Lighthouse Point, diorite of, 23.

Literature of the geology of Lake Superior, 132–157.

Lithologists who have studied Lake Superior rocks, 74.

Lithology, defects of its methods, 74; of iron district, 2, 7.

Limestone, associated with serpentine, 66.

Limonite, botryoidal ore of Pendill Mine, 51.

Lingulæ in sandstone, 26.

Locke, J., on Presque Isle serpentine, 62; metamorphic origin of Keweenaw Point rocks, 79, 80; on quartz veins, 6.

Logan, W. E., on the Calciferous and Potsdam age of the copper-bearing rocks, 94; Cambrian age of sandstone, 90; confusion of Azoic with copper-bearing rocks, 91; eastern sandstone of Chazy age, 94; erroneous statement of Houghton's views, 83; sandstone older than Potsdam, 83.

McComber Mine, minerals of, 51; geological structure of, 51.

Macfarlane, T., maintains the Permian age of the Lake Superior sandstone, 94; opposes Selwyn's views, 106.

Magnetite, octahedrons of, 30, 33; caught up by a dike, 45; dikes of, 36; altered to hematite, 39; network form of, 66; produced in the alteration of olivine, 61; surrounded by hematite films, 48; rectangular network of, 61; its relations to martite, 34, 35.

Maine, trap of, 81.

Malachite on Keweenaw Point, 76.

Manganite at McComber Mine, 51.

Marcou, J., on the igneous origin of copper, 90; maintains the New Red age of the Lake Superior sandstone, 90; copper veins dike formations, 90.

Margarophyllites in garnet, 53.

Marquette, dikes near, 36, 37, 38; sandstone of, 60.

Marquette region, Laurentian and Huronian in, 22; stratigraphy of, 19; iron ore in, 6, 7; sedimentary rocks of, 74, 75.

Masonite microscopically like ottrelite, 45.

Massachusetts, Eastern, geological methods followed in, 72.

Martite, relations to magnetite, 34, 35; octahedrons of, 33.

Marvine, A. R., on the formation of the copper-bearing veins, 103; on the concentration of the copper in the veins, 102; his geological observations sustained, 131; relation of trap and sandstone, 111; on conglomerate beds, 100; origin of amygdaloid structure, 100, 101; supports the views of Foster and Whitney, 103; his report on copper-bearing rocks, 100–103; on metamorphism, 101, 102.

Melaphyr, an altered basalt, 111; dikes of, at Coppper Falls Mine, 111, 112; frequently mined on Keweenaw Point, 111; glassy material formerly in, 125, 126; impregnated with copper, 130; locally limited, 128; microscopic examination of, from junction with jasper, 44; microscopic study of, from Washington Mine, 43; pebbles of, replaced by copper, 126; at Portage Lake, 94; relation of first lava flow to underlying sandstone, 114, 115; richer in copper near a vein, 125.

Menominee district, granite of, 24, 71; iron ore in, 3, 6, 7; Laurentian in, 22; Huronian rocks of, 22.

Metamorphic rocks, origin of, 3, 5, 6, 7, 8, 9, 10, 11, 14, 15.

Metamorphism, the agent of, 35; of crystalline rocks, 8, 9, 14, 15; exciting cause of, 27; of traps and sandstones, 101, 102; of schists, 26.

Mica, in argillaceous sandstone, 116; secondary origin of, 38; greenish, in quartz rock, 49.

Michigan geologists, defective methods of, 118.

Microcline in granite, 57.

Microlites, of apatite, 37; in feldspar and quartz, 56; in quartz, 38, 44.

Microscope, use of, in the study of rocks, 73, 74.

Microscopic analysis, insufficient to prove origin of rock, 43.

Microscopic distinction between lava flows and intrusive rocks, 111.

Microscopic examination of Lake Angeline diorite, 42.

Mineral Point Railroad, microscopic study of pebbles from, 120.

Mining, destructive of geological evidence, 68.

Montalban series in the iron region, 24.

Mud-flows in shale, 121.

Müller, A., copper reduced by organic matter and oxide of iron, 92.

Murray, A., Huronian age of iron district, 13.

Muscovite, cutting biotite, 56; folia of, in feldspar, 57; in feldspar, 56.

Negaunee, Michigan, eruptive diorite at, 41; "soft hematite" mines of, 51.

Nevadite, 72.

New England, methods of observation in, 73.

New Jersey, sandstone of, contemporaneous with that of Keweenaw Point, 79.

New Red sandstone of Upper Silurian age, 89, 90.

New York Mine, quartzite of, 59.

Newberry, J. S., on the origin of iron ores, 23, 24.

Norian, in Eastern Massachusetts, 72; eruptive basaltic (gabbro) forms, 72.

North Island, diabase and diorite of, 39.

Nova Scotia, trap of, 81.

Olivine, action of magma on, 40; alteration of, 42, 61; in diabase, 40, 42, 43, 45; foreign in basalt, 119; greenish pseudomorphs of, 61; in peridotite, 60, 61; presence of, in iron region, 75; pseudomorphs after, 36.

Ontonagon district, structure of, 104, 105.

Ontonagon River, origin of copper of, 76; sandstone on west fork of, 100.

Organic matter, precipitation of the copper by, 92, 95, 109, 130.

Orthoclase, secondary origin of, 37.

Osceola Mine, microscopic study of pebbles from, 119.

Ottrelite, microscopic characters of, 45.

Ottrelite schist, formation of, 36, 75; microscopic study of, 45; production of, 45.

Ovifak, Disko, iron-bearing basalt of, 13.

Owen, D. D., on the age of the sandstone, 84, 90.

Owl Creek Vein, mass copper of, 130.

Palæozoic age of rocks of Eastern Massachusetts, 72.

Palmer Mine, eruptive character of jasper at, 32.

Peck, Samuel, credited with first discovery of iron ore in the iron district, 4.

Pendill Mine, geological structure of, 51.

Penokee Gap, unconformability of Huronian and Laurentian at, 25; Huronian and Laurentian at, 24.

Peridotite, alteration of, 61–66; contact with sandstone, 2, 3; eruptive origin of, 64; place of, in lithological nomenclature, 65; of Ishpeming, 65, 66; of Presque Isle, 2, 3, 42, 60–65, 75; microscopic study of, from Presque Isle, 60–62; relations of, to sandstone at Presque Isle, 10.

Permian age of copper-bearing rocks, 97.

Petherick Mine, "ash-bed" at, 112.

Phœnix (old) Mine, "ash-bed" at, 112; diabase of, 111; a fissure vein, 129.

Picnic Island, diorites of, 23, 39.

Picnic Point, granite of, 39, 55, 56; microscopic study of rocks of, 39, 40; rocks of, 39, 40, 74.

Pittsburg and Lake Superior Mine, microscopic section of iron ore intrusive in quartzite, 32.

Plagioclase, cutting augite, 42.

Plasticity of iron ore, jasper, and chlorite schist, 67.

Porcupine Mountains, geological structure of, 76, 77, 84.

Porodite, use of the term, 60.

Porphyry, formation of, 84.

Portage Lake, copper deposits of, 94; dip of sandstone at, 82; melaphyr at, 94; old lava flows mined at, 124; trap at, 86.

Portage Lake district, copper deposits mined in, 128, 129; no fissure veins in, 124; "slates" of, 121.

Porter's Island, 80.

Potsdam age, of all Lake Superior rocks, 12; of iron region, 26; of Keweenaw Point sandstone, 82, 84, 87, 90, 103, 104.

Potsdam sandstone, source of materials in, 60; microscopic study of, 60.

Prehnite, igneous origin of, 80.

Presque Isle, dolomite of, 3; forming an island in the Potsdam Sea, 23; geological structure of, 2, 3, 9, 10, 23, 60; peridotite of, 75; peridotite and serpentine of, 60–65.

Pseudo-amygdaloidal structure, origin of, 100, 101, 123, 129, 130.

Pseudomorphs after olivine, 36.

Pseudo-stratification, 28.

Pumpelly, R., on alteration of basaltic rocks, 105; on black inclusions in garnet, 47; copper-bearing traps, diabases, and melaphyrs, 105; on the deposition of the copper by protoxide of iron, 97; derivation of copper from sandstone, 126, 127; geological report on the copper district, 100; pre-Potsdam age of copper-bearing rocks, 99; "specular slate ore," pseudomorph after chlorite schist, 20.

Pyrite, in felsite, 38.

Quartz, bearing fluid and vapor cavities, 38, 39, 114, 117, 119; containing double pyramidal inclusions, 120; crystals in sandstone with unworn facets, 117; devitrification form of, 33; fluid inclusions in, 43, 44, 45, 55; foreign, in rhyolite and felsite, 119; grains formed by fissuring of a silicious mass, 53, 54; heat action on, 33; inclusions in, 44, 54–59; microlites in, 38; prismatic structure of surrounding ring, 48; secondary origin of, 33, 36, 37, 38, 39, 47, 113, 114, 117, 119, 120; stone cavities in, 38, 119, 120; structure of, in felsite, 118, 119; with unworn facets in sandstone, 60; water-deposited, 63.

Quartz Porphyry, rhyolitic character of, 119. See *Felsite*.

Quartz Rock, intrusive character of, 49; microscopic study of, from Lake Superior Mine, 49.

Quartz, Veinstone, microscopic examination of, 51; fluid cavities with moving bubbles, 51.

Quartzite, of Brooks, at Republic Mountain, 34, 35; of Carp River, 9; defined by Zirkel, Lasaulx, and Hawes, 58; eruptive form of, 34, 35; eruptive origin of, 11; formed of detritus of jasper and iron ore, 59; granite intrusive in, 55; Huronian age of, 22; an indurated sandstone, 58, 59; microscopic study of iron ore intrusive in, 33; microscopic study of, from Ishpeming, 59; microscopic study of, from Jackson Mine, 59, 60; microscopic study of, from New York Mine, 59; microscopic study of Brooks's, from Republic Mountain, 54; of the New York Mine, 30; origin of, 9; overlying ore, and containing fragments of it, 32; ripple-marks in, 9, 25.

Quebec Group, Lake Superior sandstone belonging to, 93.

Quincy Mine, working on an old lava flow, 125; character of ore deposit, 129.

Raindrop impressions in shale, 121.

Republic Mountain, diorite of, 45, 47, 49; granite of, 52–55; greisen of, 44, 55; magnetic silicious schist of, 47; ore and rocks of, 34; "quartzite" of, 34, 35.

Rhyolites, felsites originally identical with, 38, 39, 118, 119.

Rhodochrosite, at McComber Mine, 51.

Ripple-marks, 9, 25, 79, 121.

Rivot, L. E., his ideas in regard to Lake Superior geology, 11, 12, 91.

Rominger, C., on the conformability of Laurentian and Huronian, 25; dikes near Marquette, 36; on the geological age of the Eastern sandstone, 122; on occurrence of "soft hematite," 50; on the Ontonagon district, 104, 105; on Presque Isle serpentine, 62; on the relation of the copper-bearing rocks to the sandstone, 103, 104; on the relation of the sandstone and quartzite, 22, 23.

Rocks, all subject to alteration, 28, 34; alteration accompanied by recrystallization, 34; alteration of, a passage from an unstable condition towards a more stable one, 125; association of, 28; banding of, no proof of stratification, 72; basic eruptive, of iron region, varieties of, 46; causes of induration of, 125; determination of age of, by lithological characters, 94; geological age, told microscopically, 73, 74; their history, 28; intrusive garnet-bearing actinolite probably altered andesites and basalts, 49; intrusive, of iron district, 70; the microscopic study of, 73, 74; mode of determining origin of, 68; names given to local modifications of, 55; original characters of, lost, 34; passage of different forms into one another, 40, 69; requirements for study of altered forms, 74; resemblance does not prove identity, 27, 28; sedimentary origin of eruptive, 11, 12; superficial study of, 69.

Rocks, crystalline, origin of, 14, 15; passage of different forms into one another, 4, 5, 14, 27, 37, 69; pre-Palæozoic age of, 5.

Rocks, eruptive, crystallization of, 72; of iron district, originally basalts, 46.

Rock structures, origin of, 28.

Rogers, H. D., copper-bearing rocks semi-fused materials, 83; on the copper deposits, 82, 83; crystalline rocks of Chocolate and Carp Rivers of Primal or Potsdam age, 4; New Red age of Keweenaw Point sandstone, 83.

Rogers, W. B., Potsdam age of sandstone, 93.

Rottermund, Count de, report of, 91, 92.

Ruggles, D., on the origin of copper veins, 80.

St. Mary's River, sandstone of, 77.

Salisbury Mine, geological structure of, 50; "soft hematite" of, 49, 50,

Salt cubes, in granite, 25; in quartz, characteristic of Huronian granite, 56.

Sand, concretions of, in shale, 121.

Sandstone, action of trap on, 82; composed of trachytic and rhyolitic material, 114, 115, 117, 119, 120; contact with quartzite, 22, 23; containing trappean detritus, 110, 111; curved stratification of, 63; formed of granite detritus, 60; formed from volcanic *débris*, 117, 118; impregnated with iron ore, 32; microscopic study of indurated, 114, 115; origin of, 122, 128; precipitation of copper in, by organic matter, 94, 95, 109; pebbles of quartzite in, 113; its relation to Presque Isle peridotite, 63, 64; its relation to the traps, 109–113, 118; ripple-marks in, 79; stalactites of, 118; thermal water action on, 63, 117; Torch Lake quarry of, 117; on western side of copper-bearing rocks, 120, 121, 122; microscopic study of feldspathic, 60.

Sandstone, Eastern, dip of, 113–119; geological age of, 122; relation to traps, 108; younger than the copper-bearing rocks, 98, 99.

Sandstone of Keweenaw Point, age of, 108; belongs to the Quebec group, 93, 97; Calciferous age of, 93, 94; Cambrian age of, 90; cause of absence of fossils in, 85; of Chazy age, 94; of "New Red" age, 79, 80, 81, 89, 90, 93, 97; of "Old Red" age, 77, 80; origin of, 82; of Permian age, 94; of Potsdam age, 82, 91, 93, 103, 104, 107; pre-Potsdam age of, 83.

Sandstone, Western, of same age as the traps, 121, 122.

Schist, composed of basaltic detritus, 37; contortion of stratification planes of, 67; garnet-bearing, of Republic Mountain, 47; granite intrusive in, 55; Huronian age of, 14, 24, 52; lamination cut by iron ore, 31; microscopic study of, 36, 37, 47, 48, 53, 58; mineralogically like diorite, 37; passage of magnesian, into dioritic rocks, 20; its relation to the iron ore, 31; sedimentary origin of, 26, 48; uplifted by granite, 53; welded to granite, 53.

Schoolcraft, H. R., falsification of original documents in his "Summary Narrative" of 1854, 10, 11; his views in regard to the copper region of Lake Superior, 76.

Schoolhouse Mine, conglomerate at, 30; dike of jasper at, 30.

Sedimentary origin of eruptive and crystalline rocks, 11, 12, 14, 15; of the iron ore, 6, 14, 15.

Sedimentary rocks, rapid deposition of, 118.

Selwyn, A. R. C., on the Huronian age of the copper-bearing rocks, 106.

Serpentine, an alteration form of peridotite, 61, 66; an alteration product of olivine, 42; on the formation of, 75; microscopic study of, from Ishpeming, 65, 66; network structure of, 61; origin of, 64, 65; of Presque Isle, 60–65.

Shale, raindrop impressions, ripple-marks, and mud-flows in, 121.

Shelden and Columbian Mine, character of copper deposit at, 129.

Silica, eruptive with hematite, 33.

Silver, its union with copper, 79, 81, 105, 106, 109.

Spherulitic structure, produced by alteration, 113, 119, 120.

Stone cavities in feldspar, 42; formed from devitrified base, 42; in quartz, 56.

Sweet, E. T., unconformability of Laurentian and Huronian, 24.

TACHYLITE, altered form of, 44.

Talc, in ottrelite schist, 45.

Teal Lake, diorite of, 41; lamination of schist at, 41; quartzite of, 9.

Thermal waters, action of, 49, 50, 51, 116, 117, 123, 124, 125, 126.

Titanite, in granite, 56.

Torch Lake, sandstone quarry at, 117.

Tourmaline, in eclogite, 48; crystals in diorite, 45; in ottrelite schist, 45; presence of, in iron region, 75; in radiating groups of crystals in quartz, 45.

Trachyte, microscopic study of, 113, 114, 117, 120; pebbles of, 113.

Trap, action on the sandstone, 86–88, 101–103; age relative to Eastern sandstone, 108; amygdaloidal and scoriaceous on upper surface, 110; characters and relations of, 104, 109–113, 118, 128; denudation of, before sandstone was deposited, 113; evidence that they are lava flows, 127, 128; pseudo-stratification of, 86; sends tongues into the "ash-bed," 113; tongues of, extending into sandstone, 110; metamorphic sedimentary origin of, 91.

Triassic age of copper-bearing rocks, 97.

Trichites in quartz, 59, 120.

UNCONFORMABILITY, based on foliation and lamination, 71; not proof of distinct age, 31.

VAPOR CAVITIES in quartz, 39.

Veins, filling of, 124, 129; of iron ore, 29; variations of, 129; width of, 124.

Veins fissure, formation of, on Keweenaw Point, 123.

Vein material, derived from the traps, 123.

Veinstones, character of best forms, 130.

Viridite, replacing augite, 42; replacing base, 37.

Volcanic action, earlier than Tertiary times, 119; gradual increase and diminution of, 122.

Volcanic origin of the copper-bearing rocks, where shown, 131; of copper veins, 80.

WARWICK, Rhode Island, masonite of, 45.

Washington Mine, rocks of, 43, 44, 45.

Washington Mine (new), dikes of ore at, 36.

Washington Mine (old), relations of iron ore and actinolite schist, 35.

Water, action of percolating, 123, 129.

Whitney, J. D., alternations in formation of zeolites, 95; chemical analysis of Presque Isle serpentine, 14, 62, 65; "Metallic Wealth of the United States," 90; igneous origin of iron ore, 7, 10; on the iron district, 7.

Whittlesey, C., copper-bearing rock continuous with, but below, the sandstone, 94; eruptive origin of granite, 24; Huronian

age of schists, 24; pre-Potsdam age of sandstone, 90.
Wichmann, A., diorite of, 37; on eclogite, 48; on feldspar crystals, 44; limits between jasper and ore, 33; on olivine-diabase, 70; on the Presque Isle serpentine, 62; report on the rocks of the iron district, 66; use of term quartzite, 58, 59; originally formed products in feldspar, 55, 56.
Winchell, A., on the iron district, 17, 18; sedimentary origin of iron ores and diorites, 17, 18.
Wisconsin geologists, defective methods of, 107, 118; on the Keweenawan series, 107.
Wright, C. E., metamorphic origin of granite, 25; origin of "soft hematite," 25; relation of Laurentian and Huronian, 25; salt cubes in quartz, 25, 56; sedimentary origin of iron ore, 25; unity of foliation and stratification, 25.

ZEOLITES, formation of, 91, 93.
Zircon crystals in quartz and feldspar, 56; in granite, 57; microlites of, in quartz, 57, 59.
Zirkel, Ferdinand, "inserted substance" a base, 37; originally formed products in feldspar, 55, 56.